

ANNUAL REPORT

INVESTIGATION OF TEST METHODS,
MATERIAL PROPERTIES, AND PROCESSES

FOR SOLAR CELL ENCAPSULANTS

(NASA-C -157939) ENCAPSULATION TASK OF THE
LOW-COST SILICON SOLAR ARRAY PROJECT.

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ENCAPSULATION TASK OF THE LOW-COST
SILICON SOLAR ARRAY PROJECT

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initiate a major effort toward the development of low-cost
solar arrays.

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CONTENTS

	<u>Page No.</u>
1. SUMMARY	1- 1
2. INTRODUCTION	2- 1
3. SURVEYS	3- 1
Pottants	3- 2
Outer Covers	3- 6
Back Covers	3- 9
Adhesives	3-10
Acrylic Materials	3-12
Substrates	3-20
4. EXPERIMENTAL WORK	4- 1
UV Upgrade.	4- 3
Plasma Spray.	4-12
Module Fabrication	4-16
Weathering Studies	4-43
5. CONCLUSIONS	5- 1
6. RECOMMENDATIONS	6- 1
7. FUTURE ACTIVITIES	7- 1

APPENDIX

CONTENTS (Continued - 2)

Page No.

LIST OF TABLES AND FIGURES

Table 3-1 - Transparent Plastics Survey, Materials Under 50 Cents/Pound	A- 1
Table 3-2 - Transparent Plastics Survey, Materials Costing 50 Cents to \$1.00/Pound	A- 3
Table 3-3 - Transparent Plastics Survey, Materials Costing \$1.00 to \$4.00/Pound	A- 5
Table 3-4 - Transparent Plastics Survey, Materials Costing More Than \$4.00/Pound	A- 6
Table 3-5 - Most Promising Transparent Polymers for 1986 Encapsulation Pottants	A- 7
Table 3-6 - Linear Thermal Expaonsion, ASTM D696	A- 8
Table 3-7 - Adhesive Cost for 5-Mil Glue Line	A- 9
Table 3-8 - Acrylic Molding Compounds	A-10
Table 3-9 - Acrylic Casting and Embedding Compounds	A-15
Table 3-10 - Solvent-Based Acrylic Coatings	A-16
Table 3-11 - Solvent Acrylic Adhesives	A-19
Table 3-12 - Acrylic Latex Adhesives and Coatings	A-21
Table 3-13 - Bulk and Hot-Melt Acrylic Adhesives	
- Part A - Bulk Acrylic Adhesives	A-29
- Part B - Hot-Melt Acrylic Adhesives	A-31
Table 3-14 - Plastic Based Substrate Materials	A-32
Table 3-15 - Metal Substrate Materials	A-36
Table 3-16 - Ceramic Based Substrate Materials	A-37
Table 3-17 - Wood Product Substrates	A-38
Table 4-1 - UV Stabilizers	A-39
Table 4-2 - Antioxidants	A-41

CONTENTS (Continued -3)

Page No.

Table 4-3 - UV Upgrade - Hardness, ASTM D-2240, Shore A and D	A-43
Table 4-4 - UV Upgrade - Optical Transmission, Ultraviolet Range 280-350 nm	A-44
Table 4-5 - UV Upgrade - Optical Transmission, Visible Range 350-800nm	A-45
Table 4-6 - UV Upgrade - Mechanical Property, Yield (psi), ASTM D-1708	A-46
Table 4-7 - UV Upgrade - Mechanical Property, Modulus (psi x 10 ⁵), ASTM D-1708	A-47
Table 4-8 - UV Upgrade - Mechanical Property, Elongation, Percent, ASTM D-1708	A-48
Table 4-9 - UV Upgrade - Mechanical Property, Tensile Strength, ASTM D-1708	A-49
Table 4-10 - UV Upgrade - Mechanical Properties, Tedlar Protection, ASTM D-1708	A-50
Table 4-11 - UV Upgrade - Mechanical Properties, UV- Acryloid Protection, ASTM D-1708	A-51
Table 4-12 - UV Upgrade - Optical Properties, ASTM D-1708.	A-52
Table 4-13 - Ultraviolet-Absorbing Coatings (Based on Rohm & Haas Acrylics)	A-53
Table 4-14 - Exposure Testing Florida, Fixed Angle, 6 months	A-55
Table 4-15 - Exposure Testing EMMAQUA Exposure, 4 months	A-56
Table 4-16 Exposure Testing EMMAQUA Exposure, 8 months	A-57
Table 4-17 Exposure Testing Elongation at Break Comparison	A-58
Table 4-18 Exposure Testing Tensile Strength Comparison	A-59

CONTENTS (Continued -4)

Page No.

Table 4-19 Exposure Testing

Optical Transmission A-60

Table 4-20 - Mechanical Property/Temperature Variation-

Ultimate Tensile Strength (psi) A-61

Table 4-21 - Mechanical Property/Temperature Variation-

Yield Strength (psi) A-62

Table 4-22 - Mechanical Property/Temperature Variation-

Modulus $\times 10^5$ psi A-63

Table 4-23 - Mechanical Property/Temperature Variation-

Elongation at Break (%) A-64

LIST OF FIGURES

Figure 3-1 - Flat-Plate Solar Module Design 3-28

Figure 4-1 - Energy Comparison and Support Data 4-15

1. SUMMARY

Springborn Laboratories is engaged in a study of evaluating potentially useful encapsulating materials for the encapsulation task of the Low-Cost Solar Array project (LSA) funded by the Department of Energy. The goal of this program is to identify, evaluate, and recommend encapsulant materials (other than glass) and processes for the production of cost-effective, long-life photovoltaic solar modules.

The report presents the results of an investigation of solar module encapsulation systems applicable to the Low-Cost Solar Array project 1986 cost and performance goals. The 1986 cost goal for a 20 year life solar cell module is \$0.50 per watt or \$5 per square foot (in 1975 dollars). Out of this cost goal, \$0.25 per square foot is currently allocated for the encapsulation in terms of raw materials, exclusive of labor.

Assuming the flat-plate collector to be the most efficient module design, six basic construction elements were identified and their specific uses in module construction defined. In order to generate a comparative analysis, a uniform costing basis was established for each element. Extensive surveys into commercially available materials were then conducted in order to identify either general classes or specific products suitable for use for each construction element.

The survey results were also useful in revealing price ranges for classes of materials and estimating the cost allocation for each element within the encapsulation cost goal.

Due to the cost constraints, material deficiencies and development areas also became apparent.

The six construction elements were considered to be substrates, superstrates, pottants, adhesives, outer covers and back covers. Substrates and transparent superstrates are the structural or load-bearing components and will consequently be found in all module constructions.

From the first-cut material cost allocation based on \$0.25 per square foot developed for the six construction elements, substrates were subsequently assessed to be approximately 60 percent of the encapsulation expense. A survey of four classes of candidate substrate materials - including ceramics, plastics, metals, and wood - singularly identifies wood and paper composites as the lowest costing materials for this application. A commercially available hardboard showed a calculated cost (at the required thickness) of \$0.13-0.14 per square foot.

Commercial soda-lime (window) glass is twice as expensive at \$0.29/ft.² and the lowest costing metal, mild steel, is three times the cost at \$0.42/ft.². Plastic materials were the most expensive class surveyed, the lowest prices at \$0.52 to \$0.55/ft.² for styrene-maleic copolymer and mineral filled polypropylene compounds. The next price level was found around \$1.00/ft.² for filled polyethylene and PVC compounds, then ranging to \$4.08/ft.² for NEMA G-10 epoxy board, a popularly used substrate. No ceramic or inorganic materials, except for glass were found to be suitable candidate substrates at this time due to cost and poor weatherability. For superstrates, a flat transparent acrylic plate is a widely considered choice, however the high cost of \$1.77/ft.² at the required thickness makes it unusable. Glass is still the most viable transparent and structural material for superstrate bonded cell constructions.

Pottants are the second most important construction element, demanding an estimated 25% of the materials allocation. Silicones, fluorocarbons and acrylics are the only inherently weatherable polymers discovered to date. Fluorocarbons and silicone products are too expensive (\$9-12/lb.) for use; however, and fluorocarbon polymers are processable only at prohibitively high temperatures (600°F). The silicone rubbers are easy to use (pour and cure) but the calculated encapsulation cost is \$0.48/ft.² (RTU-615). A silicone gel, Q3-6527 is available at \$3.75/lb. but still costs out to \$0.18/ft.². This material is also extremely soft and offers no structural strength. The high modulus cover required for its use would constitute an additional expense. Only the acrylics offer relatively low cost, high weatherability and the potential for appropriate processing techniques. No commercially available pourable or processable acrylic elastomers that could be use as pottants have yet been found; however, research indicates that they are developable from low-cost acrylic monomers at an estimated cost of \$1.40 to \$1.50/lb.

A number of commercially available transparent polymers ranging from \$.30 to \$1.60/lb. with suitable processing characteristics have been identified. Of major interest currently are ethylene-vinyl acetate, ethylene-propylene rubber, polyvinyl chloride plastisol and modifications of acrylic hot-melt compounds. These polymers, except for acrylic, all have a common weathering deficiency-sensitivity to UV oxidative degradation. Compounding or coating with vehicals containing UV stabilizers may alleviate this difficulty and result in viable, cost-effective candidates. The encapsulation costs of these materials are estimated to be \$0.06/ft.²).

As protective covers (i.e., outer coatings and under coatings). the acrylics are excellent candidates - presenting low cost, a variety of application techniques, outdoor durability, and compatibility with ultraviolet light screening agents.

This class of plastics was given particular attention due to its versatility and many grades were surveyed for use as various construction elements.

Low-cost coatings to screen out deleterious ultraviolet light from UV sensitive pottants were investigated, at costs of approximate \$.01/ft.². One-mil coatings of acrylic resin containing UV absorbers were prepared in the laboratory and found in several cases to have zero percent ultraviolet transmittance. Experiments with exposing coated specimens of polypropylene to ultraviolet radiation demonstrated fifteen-fold increases in the resistance to degradation. These coatings may permit the use of low-cost, UV-unstable materials as encapsulants if enough protection can be provided.

A study was also conducted on upgrading selected pottant materials with internally compounded stabilizers to impart better stability to optical and mechanical characteristics upon weathering. The task was successful in the case of optical properties, but tensile strength and elongation were much lower than the control values both before and aging. Celulose acetate butyrate was the most conspicuous success. Aged specimens that had previously melted and/or degraded to the point of destruction remained intact. Although this polymer will not be recommended as a pottant, it serves to demonstrate the feasibility of this approach.

This report emphasizes surveys of encapsulant materials; however, some studies of potentially useful processing methods were also pursued.

The plasma-spray process of applying conformal coatings received attention due to its potential for high speed automatic array processing, but it proved to be unsuccessful in laboratory trials on miniature modules.

In order to demonstrate the utility and processability of various encapsulant materials identified in this study, prototype modules were built and submitted to JPL for qualification testing. The materials of construction included flakeboard, hardboard, galvanized steel, and plywood as substrates and the following pottants: ethylene-propylene rubber, ethylene-vinyl acetate, acrylic hot-melt adhesive, and polyvinyl chloride plastisol.

Due to the increasing importance of wood and paper products for substrates, an investigation of waterproofing and preservation techniques are needed to optimize the useful life of these products. Mechanical engineering will also be required to generate high strength to weight designs to increase the cost-effectiveness of load-bearing structures.

The recently identified transparent pottants lie within the required processing and cost requirements, however the methodologies for upgrading the UV and weathering resistance need expanded investigation. These two areas of substrate design and UV upgrading are envisioned to be major technology developments required towards the successful use of low cost materials for the LSA program.

Based on data obtained so far on material options, development directions, and design concepts, the realization of the \$0.25 per square foot cost goal appears to be attainable, however the lifetime of these systems needs to be demonstrated.

2. INTRODUCTION

The goal of this program is to identify and evaluate excapsulation materials and processes for the protection of silicon solar cells for service in a terrestrial environment.

Encapsulation systems are being investigated consistent with the DoE objectives of achieving a photovoltaic flat-plate module or concentrator array at a manufactured cost of \$0.50 per peak watt ($\$5/\text{ft}^2$) (1975 dollars), with a projected first year production rate of 500 peak megawatts. This project has a target date of 1986.

To insure high reliability and long-term performance, the functional components of the solar cell module must be adequately protected from the environment by some encapsulation technique. The potentially harmful elements to module functioning include moisture, ultraviolet radiation, heat build-up, thermal excursions, dust, hail, and atmospheric pollutants. Additionally, the encapsulation system must provide mechanical support for the cells and corrosion protection for the electrical components.

Module design must be based on the use of appropriate construction materials and design parameters necessary to meet the field operating requirements, and to maximize cost/performance.

The materials cost for encapsulating a 1986 module was targeted at 25 cents per square foot, (or $\$8/\text{meter}^2$, including frame) with the encapsulation system providing protection to assure outdoor system performance for at least 20 years. Successful system performance was defined as a decay in electrical power output not exceeding 50 percent of original value.

Assuming the flat-plate collector to be the most efficient design, nine different basic design variations have been considered (Figure 3-1) from which three primary types may be envisioned:

- . Substrate Bonded: cells bonded to rigid substrate with transparent pottant and top cover.
- . Superstrate Bonded: Cells bonded to under-side of transparent superstrate with optional top cover and with back side pottant and optional back cover.
- . Laminated; rigid single transparent laminating encapsulant with optional top cover.

All modules are variations of one of these three types and in addition employ one or more of six recognizable construction elements.

These elements are (a) outer covers, (b) structural and transparent superstrate materials, (c) pottants, (d) substrates, (e) back covers, and (f) adhesives.

Extensive surveys are being conducted into many classes of materials in order to identify a compound or class of compounds optimum for use as each construction element. Properties being considered are cost, transparency, weatherability, and applicability of processing. Additional critical properties include dielectric strength, reflectivity and heat transfer characteristics.

The results of these surveys are also used in generating first-cut cost allocations for each construction element, which are estimated to be:

<u>Construction Elements</u>	<u>Cost Allocation (\$/Ft²)</u>
Substrate/Superstrate	0.14
Pottant	0.06
Adhesive	0.04
Outer cover	0.01
Back cover	0.05

These figures reveal the most expensive cost elements to be substrate materials and pottants - and consequently they are also the elements demanding the most emphasis and study. The terms substrate and superstrate refer to the method of mechanical support used for the cells. Substrates support the underside of the cells; superstrates carry the cells on the sunlit side, and are consequently transparent. Because the silicon cells are extremely brittle and crack on flexing, mounting to a rigid and load-bearing surface is a requirement for all solar cell modules.

Pottants are conceived as low-modulus, transparent coverings over the cells, providing mechanical and environmental protection and electrical isolation. Potting compounds must also have certain processing conditions; being fabricable below the melt temperature of the cell metalization and not causing cell fracture.

This report presents the results to date of an ongoing study of potentially useful substrate materials and potting compounds. The cost-effectiveness of these materials is compared from the findings of a uniform costing exercise based on density, cost per pound and thicknesses required for realistic use. A survey was also included of many varieties of commercially available acrylic compounds. These products are very versatile and may possibly have use for any one of the construction elements.

Experimental activities of the past year are also presented and are concerned principally with the improvement of material properties and an exploration of techniques useful for successful module fabrication.

An important task was the investigation of ultraviolet light stabilizers, antioxidants, fillers, and other techniques to improve the weatherability and to extend the environmental life of materials having low UV resistance. Through the use of these processes, otherwise unweatherable materials may become cost-effective candidates in the LSA program.

Candidate pottants and outer covers have been exposed to environmental weathering in Florida and Arizona and additionally to EMMAQUA (Desert Sunshine Exposure Tests, Inc.) to observe the effects of natural and accelerated outdoor aging. The materials were exposed as tensile bars in order to assess the deterioration of physical properties with time and exposure. A base of real experience with degradation, material failure and accelerated aging results from the work.

Prototype cell modules were encapsulated with combinations of materials identified in the surveys as exhibiting promising properties and have been submitted to JPL for qualification testing. It is anticipated that specific problems relating to encapsulation materials, costs, and processes will result from this study.

3. SURVEYS

The division of flat plate solar collectors into basic construction elements provides an improved approach for the successful selection of potentially useful materials. These construction elements are considered to be pottants, outer covers, back covers, adhesives, substrates and superstrates.

Surveys of materials were conducted by defining the functions and desired material properties of these components and then investigating commercial suppliers for the most likely candidates. Information was drawn from a wide variety of sources including company brochures, manufacturers' recommendations, marketing department, plastics catalogs, telephone calls to suppliers and internal experience. The results are presented in tabulated form (Appendix) and include comparative figures on cost and physical properties.

Particular emphasis was given to substrates and pottants with rationale that these two components will be found in all module designs and also constitute the major portion of the raw material expense. Acrylic compounds also received particular attention due to their potential use for a number of construction elements. This section presents an accumulation of the material surveys conducted to date and an overview of the underlying design and function concepts. The materials' prices quoted in this report were current during the period from October 1977 to February 1978.

A discussion of each construction element follows:

POTTANTS

Without protection from ultraviolet, the classes of candidate potting materials are limited to fluorocarbons, silicones, and acrylics. The first two are extremely expensive and, in the case of fluorocarbons, entirely unprocessable without prohibitively high temperatures.

The silicone rubbers have excellent processing characteristics, being pourable and amenable to cure at room temperature, but the cost of \$8 - 9/lb. may easily exclude them from use. The many acrylic compounds available have desirably low prices but to date no commercial products exist in an elastomeric or usable form from directly encapsulating cells.

The possibility of developing weatherable and UV screening protective films and coatings permits a much broader range of polymers to be considered for potting applications. It may be possible to use a cost-effective but otherwise unweatherable polymer successfully as a pottant provided that sufficient external protection is supplied. With this idea in mind and in the interest of thoroughness, all commercially available transparent polymers were surveyed and tabulated (Tables 3-1 through 3-4) - see Appendix. The four survey tables were constructed according to price range, the ranges being: under \$0.50 per pound (3-1), \$0.50 to \$1.00 per pound (3-2), \$1.00 to \$4.00 per pound (3-3), and polymers costing in excess of \$4.00 per pound (3-4). The tables are set up to include in the first section a description of the polymer - i.e., its generic chemical type, at least one of its trade names, and the manufacturer. A given polymer is often available through many other producers, but for the sake of convenience only one has been listed.

The polymers surveyed encompassed a great variation in physical properties and chemistry and included such materials as the following: polyvinyl chloride, polystyrene, polyethylene, polyesters, ionomer, polyamides, cellulose, urethanes, silicones, etc.

The following section of the table then describes processability as being either in liquid or solid form. Liquid signifies a casting process. In the solid class, the fabrication temperature is shown as either less than (<) or greater than (>) 250°F (a few are at 250°F). It is essential that the fabrication (extrusion, compression molding, injection molding, thermoforming) temperature be below 350°F to avoid melting the solder and to avoid the need for high forming pressures that would crack the brittle silicon cell. The 250°F temperature is an approximation and should allow a sufficient safety factor.

In the central portion of the table is a column showing the survival prognosis; this involves the survival span in years of unprotected materials. In the next column is shown an upgrading potential in years of completely protected polymers. By complete protection we imply a high level of an internal UV additive synergistic system and a film or coating containing a high level of UV absorber to screen out the impinging UV light. All of these figures are educated opinions, based on experience with related materials since this type of specific information is rarely available. The years predicted for the virgin polymer are given in ranges and those for the protected polymer as Fair (F) or Good (G) at 10 and 20 years of lifetime.

The following portion of the table contains literature information on properties - hydrolysis resistance (educated opinion), tensile modulus, refractive index, density, and coefficient of thermal expansion. We chose what we considered to be the most important properties. Stiffness (modulus) is critical to fabrication; if there is too much stiffness, the polymer would require such a high pressure to be fabricated that it would crack the cell. In addition, a soft, rubbery plastic appears to be necessary to absorb stress generated by the difference in coefficient of thermal expansion between inorganic silicon and an organic polymer.

The final (extreme right) portion of the table covers costing in terms of cost per pound, cost per volume as \$/cubic inch, fill (space between cells) cost as \$/square foot, and the cost for an additional 5-mil (0.005 inch) protective covering for the cell. The fill cost is calculated as-

suming the cells are 10 mils thick astride a 5-mil glue line (for a total of 15 mils thickness) and that the void space requiring pottant is 31 volume percent. The total encapsulant cost is the sum of the fill and the cover costs.

These arbitrary fill and coverage conditions were selected to provide a uniform pottant costing basis for comparative analysis, and it is recognized that design variations such as decreases in cell and glue line thicknesses, pottant thicknesses, increased cell packing density, etc., will influence material cost. The total encapsulant costs appearing in Tables 3-1 through 3-4 provides a degree of general information regarding transparent materials; 40 percent of these cost less than \$0.03 per square foot and 50 percent cost less than \$0.05 per square foot.

Among the 50 percent of the surveyed materials which fall within the cost range of \$0.01 to \$0.05 per square foot, no transparent material which could survive unprotected for 20 years outdoors has been identified.

The lowest costing commercial transparent material which could have immediate candidacy for LSA is the silicone gel (Q3-6527, Dow Corning), combining high transparency, processability and UV stability. This polymer costs out at \$0.18 per square foot.

Currently existing weatherable fluorocarbon and silicone products are high-priced (\$0.44 - 2.00/ft.²), but acrylics will become viable candidates if suitable elastomeric products can be developed. Castable acrylic elastomers are estimated at a cost of \$0.06 to \$0.07 per square foot.

A condensation of the list of transparent polymers into a small group of materials appears in Table 3-5 (Appendix); these materials are, or at least have the potential of being, easily processable. This table is divided into two groups: those polymers that can be cast and those that are fabricable below approximately 250°F. Only those polymers are included in this table whose all-around properties offer chance of success. By this is meant:

- a. The price must be reasonable.
- b. Stiffness/modulus must be relatively low.
- c. The polymer must be processable.
- d. There must be a reasonable possibility that the polymer can be upgraded to last 10 years and hopefully 20 years through internal (stabilizers) and external (coatings) protection.
- e. The polymer must have reasonable physical properties. This rules out, for example, the inexpensive but brittle hydrocarbons from Neville Chemical.
- f. The polymer sheet must be transparent.

The principal example of casting resin is the presently used silicone. The silicones have the obvious disadvantage of price (\$0.2-0.40/ft.²). Cast acrylics are much lower in cost, but much too high in modulus. Care must be taken to select a casting resin that is flexible - i.e., one having a relatively low modulus - to provide stress relief because of the difference in coefficient of thermal expansions between silicon and polymer. Mismatch of thermal expansions between cell and pottant is an unavoidable problem that can only be overcome with the use of soft materials. As Table 3-6 shows, polymers have ten to 100 times the expansion coefficients of silicon. Thermal excursions are also obviously unavoidable as the module cycles between day and night exposures. The system must be designed to "give" as stress differentials appear.

The only pourable casting materials presently being considered for experimental module construction are polyvinyl chloride, plastisol and a modified acrylic hot melt adhesive.

The solid, low-melting ethylene copolymers (ethylene/vinyl acetate; ethylene/propylene rubber) shown are not stable to UV; but with both internal compounding protection and external screening, they offer the possibility of a long-term encapsulant. Additionally, it is felt that these polymers offer wide latitude in the types of processing

techniques (i.e., injection molding, compression molding, hot melt coating, vacuum lamination, etc.) that may be employed for their successful use. Table 3-5 is a first-cut effort at suggesting low-cost, viable candidate pottants for 1986. The average price of materials in this table is about \$0.04 per square foot. It is recognized that the viability of these polymers remains to be demonstrated and their successful use will be dependent on the efficiency of protective films and/or internal stabilizers.

OUTER COVERS

As discussed in the previous section, soft elastomeric pottants are necessary to prevent cracking of silicon cells due to thermal expansion differences. Such soft materials are prone to soiling and dust retention, however, which reduces the light transmission and impairs cell efficiency. Hard coatings are therefore necessary to avoid this problem.

In current module designs, outer covers are already serving as soil and mar resistant coatings over lower modulus pottants which are susceptible to permanent retention of dust and dirt. An example of this usage is R4-3117 (Dow-Corning) coating over soft silicone rubber pottants. Coatings of several mils thickness with moduli greater than 20,000 psi appear to be adequate for this purpose.

An additional function for coatings is anticipated; that of UV screening to provide weathering stability to the underlying pottant. Examination of Tables 3-1 through 3-5 reveals that no low-cost, inherently weatherable transparent polymers useful as pottants exist. Acrylics are an exception to this observation, being intermediate in price; however, no usable (low modulus) forms exist.

Low-cost elastomeric pottants which are UV sensitive may become viable if sufficient protection can be provided by the outer cover or coating.

Polymers degrade upon exposure to weathering with loss of optical transparency and deterioration of physical properties such as tensile strength and elongation. The primary chemical modes of weathering are:

1. Hydrolysis (chemical reactions with water)
2. Thermal oxidation
3. Ultraviolet light absorption
 - a. UV photolysis
 - b. UV photo-oxidation
 - c. UV synergised hydrolysis

No polymer coatings can be formulated to provide protection from the first two modes. All polymers are transmissive to water vapor and oxygen, the only variation being that of diffusivity or rate of permeation. Elastomeric materials that are very sensitive to hydrolysis or thermal oxidation cannot be considered as useful candidates because there is no way to protect them.

Polymers sensitive only to UV reactions are a possibility, however. Experiments at Springborn Laboratories have demonstrated the possibility of compounding UV absorbers into acrylic films so that all ultraviolet is cut out (see Table 4-3). Coatings of these films over UV-sensitive polymers should prevent degradation reactions from occurring, or slow the process down to an acceptable rate.

By the nature of its position on the surface of the module, the outer cover must in itself have high weatherability in addition to serving as a vehicle for UV absorbers. Four inherently weatherable transparent materials have been identified to date: glass, fluorocarbons, silicones, and acrylics. All four are potentially useful UV-absorbing vehicles; however economic constraints also become evident upon basic cost analysis. The following list is a comparison of potentially useful outer covers:

<u>Material</u>	<u>Type</u>	<u>\$/Pound</u>	<u>Estimated Array Cost (\$/Ft²)</u>
R4-3117	Silicone	9.735 (solids)	0.12
Tedlar-UT ^(a)	Fluorocarbon	5.75	0.09
Glass	Glass	-	0.30
FEP	Fluorocarbon	11.00	0.24
Llumar ^(a)	Polyester (special)	-	0.22
Acryloid B82	Acrylic	1.02	0.01

(a) contains UV absorbers

The only coatings that are comfortably tolerated by the 1986 materials cost goal of \$0.25/ft² are the acrylics and perhaps thin glass. Fortunately there exists an enormous number of these acrylic products available in brushable and sprayable forms such as latex (water-emulsion based) and solution grades (solvent based) that may serve as UV screening vehicles. Rohm & Haas Company, the primary manufacturer of these acrylics, has exposed coatings to more than twelve years of outdoor weathering without any visible evidence of deterioration⁽¹⁾. Experiments at Springborn Laboratories with acrylic coatings show equally successful performance.

A possible problem foreseeable at this time is the leaching or exudation of UV absorbers and stabilizers, with subsequent reduction of the protective properties of the outer cover. Industrial development is currently under way in the areas of polymeric antioxidants and UV absorbers. These compounds should demonstrate extremely low extractability due to their high molecular weights. Another approach is to synthesize additives containing copolymerizable vinyl groups that chemically become part of

(1) Rohm & Haas, "Thermoplastic Acrylics-Exposure Series 57YY"

Memo 51-1243; May 14, 1969; Quoted by Permission.

the polymer matrix. An example of this concept is a UV absorber called Permasorb-MA (National Starch and Chemical Corporation) which may be polymerized with any addition-type monomers, such as acrylics and vinyl based compounds.

One-mil thick fluorocarbon and silicone films are still viewed as too expensive for 1986, but are not being eliminated from consideration. DuPont's UV absorbing film designated Tedlar UT costs \$0.048 per square foot per mil, (based on the 5-mil thickness) and may be permissible for use if other construction elements are of sufficiently low cost.

The development of highly efficient and cost-effective UV screening coatings is currently viewed as an important technology area for LSA, and may be instrumental in achieving the required cost goals.

BACK COVERS

Back covers are special construction elements used only in superstrate bonded module designs. In this type of construction the sunlit sides of the solar cells are bonded (with transparent cement) to the clear superstrate, and the backsides remain to be protected. This cover, or combination of covers, must basically provide electrical and corrosion protection and have the property of stress relief (low modulus).

This element may consist of a single conformal coating or a combination of pottant and film overlay. Any of the films, coatings, and pottants previously discussed in this section may be used for this element, but with the additional advantage that clarity is not a requirement. This permits low-cost polymers to be used with stabilizing fillers such as carbon black and iron oxides; and extenders (to reduce cost) such as clay, talc, and wood flour. Although carbon black is a highly efficient stabilizer, its use might be precluded by heat buildup resulting from its high solar absorption. An alternative approach is to use zinc oxide or titanium oxide which are white in color and highly reflective. Suitable candidates should appear from already identified polymers costing approximately \$0.05 per square foot.

The most cost-effective superstrate, soda-lime glass, now costs approximately \$0.30 per square foot. The outstanding weatherability of glass and the possibility of reduced production costs keep this as a material of interest.

To date, this construction element has received only minor attention.

ADHESIVES

Adhesives may prove to be important components in the manufacture of solar cell modules. Some mechanism must provide for the high-reliability fastening or attachment of the other construction components to each other.

Various necessary properties of adhesives may be assumed, the first being flexibility. It is highly unlikely that an exact match in the coefficients of thermal expansion between two construction elements will occur, consequently the adhesive must demonstrate some stress relief ability. The stress cycling from thousands of thermal excursions during the life of the module must be provided for and is particularly necessary in the use of adhesives bonding the cells to the substrate or pottant.

Silicon has a very different expansion coefficient from organic materials and consequently constitutes an area requiring high stress relief. Experiments at Springborn Laboratories have shown that solar cells bonded with very high modulus epoxy and acrylic adhesives fractured after a small number of thermal cycles.

Additionally, transparency is a requirement where components are being bonded above the cell surface. Between cell and substrate an opaque glue may be used.

Weathering effects are reduced as the adhesives reside on the interior of the module and are not directly in contact with the environment. Some protection from UV degradation should be conferred from the presence of the outer coating, however, materials demonstrating notable sensitivity to this condition should be avoided. Adhesives sensitive to hydrolysis or water solubility should also be avoided due to the diffusion of water vapor which cannot be prevented.

Adhesives are commercially available in many forms and are formulated for an enormous variety of end uses. For the rapid and automated production of solar cell modules, some constraints may be suggested:

- (a) No volatile by-products may be generated during processing, curing, or during service.
- (b) All adhesives must be low in modulus, be compliant, or be able to accommodate stress relief.
- (c) Adhesives used above cell surfaces must have high transparency.
- (d) Adhesives must be readily processable and applicable to module surfaces.

The adhesives industries are currently in the process of developing non-gassing, rapid-cure systems for high-volume automated production in industries such as automotive and aircraft. Second-generation acrylic adhesives are a typical example of this class (see the following section on "Acrylic Materials"), and may be well suited to solar module fabrication. An additional desirable feature of these compounds is that they cure by polymerization and have the ability to chemically react with the mating surfaces (provided abstractable hydrogens or vinyl bonds are available), generating a strong permanent bond.

A first-cut estimate of adhesive costs was generated by pricing out some conventionally used adhesives and calculating the cost per square foot based on a 5-mil glue line. Table 3-7 lists five commercial adhesives, two epoxies, and three silicones - showing the cost per square foot for 5-mil glue lines. The silicone adhesives price out from \$0.09 to \$0.10 per square foot, the epoxy adhesives price out at a little over \$0.03 per square foot; the acrylic adhesives price out at about \$0.008 to \$0.02 per square foot.

These compounds are representative only and do not constitute recommendations. Extensive surveys of commercial adhesives with specific application to the encapsulation task are being conducted presently.

Constructions are foreseeable which would use no adhesives. These modules would employ crosslinkable pottants that would chemically bond to both substrate and cover film during the cure cycle. In the interest of speed, reducing the number of construction elements, and lowering the cost, this would be a preferred approach.

ACRYLIC MATERIALS SURVEY

At the onset of this program, Springborn Laboratories identified four classes of transparent weatherable materials: glass, silicones, fluorocarbons, and acrylics.

Of these four materials, acrylics alone stand out as having the most favorable cost/performance characteristics. Commercial acrylic polymers average \$0.80 to \$1.50 per pound (molding grade), have high optical clarity, good weatherability and a wide range of processing requirements. A multitude of grades are also available with potential for use as adhesives, potting compounds, back covers and top coatings in the construction of solar modules.

Although glass is low in cost (approximately \$0.25 per pound or 29 cents per square foot at 90 mils), its processing characteristics demand high fabrication temperatures and its effective use is limited to that of a substrate. Fluorocarbon polymers such as Teflon-FEP (DuPont) also have unusually high processing temperatures, and their price range of \$6 to \$20 per pound makes them prohibitively expensive for use as a major construction element. Clear silicone elastomers are easily used potting compounds but are also expensive at \$9 per pound. Filling the void between the cells and adding a 0.05-inch covering calculates out to approximately \$0.25 per square foot, or the entire 1986 raw materials allocation. Using the same module design for comparative cost purposes, the equivalent encapsulation cost comes to approximately \$0.08 per square foot for an acrylic-based potting compound.

Acrylic polymers are a broad range of plastics covering a wide variety of properties, available forms, and uses. They are marketed in both thermoplastic and thermoset forms - as molding pellets, fine powders, solvent-based coatings, emulsion-based coatings, cast sheet, and adhesive materials. The most outstanding characteristic of acrylic plastics is that they are the only class of polymeric compounds that are

relatively low in cost and have high inherent weatherability. They are transparent to natural sunlight (have low absorption of-ultraviolet radiation within these wavelengths) and maintain physical strength and light transmittance properties after years of exposure to weather, salt spray, and mildly corrosive atmospheres. Outdoor exposure tests on transparent, unpigmented samples of homopolymer show average transmission losses of about 1 percent over a period of five years.

The major constituent of most commercial acrylic plastics is polymethyl methacrylate. Unmodified acrylics are transparent and extremely stable against discoloration. They exhibit good dimensional stability and offer desirable structural and thermal properties. They also demonstrate good resistance to weather, breakage, and chemicals, and are light in weight.

Modified acrylics are available for applications requiring improvements in specific properties, such as toughness; are amenable to variations in copolymer composition; and can be blended with impact modifiers, reinforcing fillers, and other polymers. (In contrast to other plastics, acrylics will frequently show a loss in durability with the incorporation of a pigment; the additional surface area provided by a pigment provides sites for water and sunlight to initiate degradation by free-radical formation.)

Colorless acrylic stock has a white light transmittance of 92 percent and an average haze value of 1 percent; consequently, it is an excellent contender for applications where high transparency is required.

The hardness of thermoplastic acrylic polymers may be controlled by the selection of monomers used in the polymerization process. Properties ranging from tacky high-viscosity fluids to hard, brittle materials may be obtained. An alternate way to improve hardness and toughness is to introduce a crosslinking mechanism and cause the polymer to thermoset. Crosslinking increases room-temperature hardness and produces a polymer that demonstrates a toughness over a very broad temperature range. Cross-

linking also improves solvent resistance and prevents the polymer from creeping under heat and load conditions.

Acrylic parts exhibit good dimensional stability within their useful temperature ranges; however, some deformation may occur at temperatures slightly below the softening point (usually around 250°F). Deformation from solar heat absorption (Plexiglas windows) has not been observed.

As with most unfilled plastics, the acrylics have relatively large coefficients of thermal expansion ($6-10 \text{ in./in.}^\circ\text{C} \times 10^{-5}$), and consequently provisions must be made for expansion differentials - especially with thick parts or wide temperature ranges.

Transparent acrylic coatings may serve as vehicles for ultraviolet screening agents and serve as protective coverings for other materials. Recent developments at Springborn Laboratories have demonstrated the viability of this approach. High levels of screening agents (e.g., Tinuvin-P, 5 percent by weight) have been incorporated into solvent-based acrylic lacquers (e.g., Acryloid B-83, Rohm & Haas) to yield coatings that have a zero percent integrated total ultraviolet transmittance in films only 1 mil thick. Experiments in retarding the degradation rate of polypropylene with these coatings are proving the efficacy of this approach. Additionally, unsupported films of these coatings are also being exposed to accelerated aging conditions. Cost effectiveness is suggested from a calculated cost of approximately 1 cent per square foot per mil.

Acrylic polymers are produced in many forms to serve a multitude of functions. A survey performed by Springborn Laboratories has identified and tabulated the following commercially available transparent forms:

A. Acrylic Molding Compounds - Table 3-8

These acrylic molding compounds are resins usually occurring in pellet form and are designed for extrusion, compression, or injection molding. A multitude of grades are available, varying in melt flow, impact resistance, toughness, etc.

B. Casting/Embedding Compounds - Table 3-9

These compounds are manufactured in liquid form and are designed for room-temperature casting with subsequent curing at elevated temperatures. They are usually mixtures of polymer and monomer (both methyl methacrylate based) blended to form a medium-viscosity, clear liquid. The "syrup" is mixed with a free-radical initiator prior to use and is deaerated before casting into the desired mold. Cure times are typically from one to several hours.

C. Solvent-Based Acrylic Coatings - Table 3-10

These are polymers formulated especially for film-forming ability and solvent compatibility. Grades vary according to solvent composition, percent solids, surface hardness, and glass transition temperature.

Since polymers with overly high molecular weights provide solutions of low solids content and unworkably high viscosities, an alternate solution is to introduce crosslinking to obtain improved properties. The advantages offered over thermoplastics in this approach are:

- . Improved toughness and hardness
- . Resistance to softening at higher temperatures
- . Better resistance to solvents and moisture
- . Lower solution viscosity and higher application solids
- . Better compatibility with substrate materials

Solvent-based thermoset resins may be applied by conventional coating methods, dried, and cured through an oven cycle to produce the ultimate properties.

D. Solvent-Based Acrylic Adhesives - Table 3-11

These compounds are very similar to the solvent-grade coating resins except that they are formulated for high surface tack,

higher flexibility, and contain adhesion-promoting chemical groups. They are also available in both thermoplastic and thermoset forms and require a bake cycle to develop optimum adhesion.

E. Acrylic Latex Adhesives and Coatings - Table 3-12

Emulsion polymers consist of discrete spherical particles of high molecular weight polymer dispersed in water. Since the polymer particles are separate from the continuous aqueous phase, the viscosity of the dispersion is relatively independent of the polymer's molecular weight. Consequently, molecular weight can be raised to high levels to take advantage of the resulting improvement in performance properties.

Viscosity remains conveniently low and permits wide formulating latitude. Because of their molecular weight advantage emulsion polymers exhibit good toughness, chemical and water resistance, and outdoor durability characteristics. Also, they allow the highest application solids (up to 70 percent).

F. Bulk and Hot-Melt Acrylic Adhesives -
Table 3-13, A and B

The bulk adhesives survey encompasses four types of acrylic compounds: hot-melt adhesives, cyanoacrylates, first-generation adhesives, and second-generation (or reactive) adhesives.

Hot-melt compounds are simple low molecular weight, high surface tack solids that melt to form viscous fluids at temperatures around 150°C. They are noncuring, low-modulus, soft thermoplastic resins and have the advantage of being pourable at temperatures that will not destroy cell functioning.

Cyanoacrylates are a unique class of materials that derive their unusual behavior from a high polarization of the unsaturated bond of the acrylate. They have the ability to polymerize very quickly at room temperature with no catalyst

required. They are suitable for a number of adherends because of the presence of a number of basic materials on most substrates that may serve as activators for the polymerization. They are very expensive and are often difficult to handle due to their rapid cure time.

First- and second-generation adhesives are both members of a class called "modified acrylics", which refers broadly to solutions of rubbery polymers in methyl methacrylate. Both demonstrate excellent lap shear values (approximately 3500 psi), as well as high impact strength and transparency in thin sections. Both cure by a free-radical mechanism, but first-generation adhesives require heat for this purpose.

The term "second-generation acrylic" refers specifically to graft polymerization technology, which is based on a combination of new modifying polymers for acrylics and a surface-applied activator. The new modifiers reinforce and toughen the bond and also provide reactive sites that, in the presence of specific activators, catalyze the graft polymerization of the reactive fluids. Adhesion occurs when the monomers, under the influence of an activator, are induced to graft polymerize on the modifier in the glue line. The bond is usually complete in 2-4 minutes at room temperature, as opposed to approximately 120 minutes at elevated temperatures for first-generation materials.

Both adhesive systems supply high-strength structural bonds and demonstrate the following desirable properties:

- . Simple no-mix application
- . Tolerance for oil-contaminated or unprimed surfaces
- . Bond flexibility
- . High peel and lap shear strengths
- . Good heat and moisture resistance

- . Wide latitude in cure rate
- . Very rapid cure possibility

Acrylic molding resins (Table 3-8) are only useful in film form as outer covers or back covers. The expense involved for panels of the required thickness precludes their use for either substrate or superstrate functions, and they are all too high in tensile modulus to serve as pot-tants. Additionally, only one commercial solid-grade resin, Acryloid B-82 (Rohm & Haas), has been found to process at temperatures (275°F) that will not damage cell function. Cells directly encapsulated in this resin eventually crack, however, from mismatched coefficients of thermal expansion.

As coatings, covering a low-modulus pottant, the extruded resins should perform exceptionally well, at an average cost of approximately \$0.004/ft²/mil. Films of 0.005 inch thickness would cost 2 cents per square foot for outer covers; and of 0.01 inch thickness as a back cover would cost 4 cents a square foot. At this time, only one commercially available acrylic film is known: Korad (Xcel Corporation), priced at \$0.047 per square foot (Grade A-CV, 0.003 inch). These prices are within the estimated 1986 cost allocations for the construction elements mentioned.

Solvent-based coatings (Table 3-10) are a little more expensive - averaging about \$0.006/ft²/mil (dry film), due to the formulating necessary for solution compatibility. An advantage is that they may be applied to a surface and subsequently dried and crosslinked at an elevated temperature. A disadvantage is that the solvent present may interfere with the surface being treated; also, a drying cycle is required to deposit the film - possibly in multiple applications - to achieve the desired thickness.

Solvent-based coatings are compatible with many ultraviolet-absorbing compounds and may serve as useful vehicles for UV screening covers. Latex (emulsion) based coatings (Table 3-12) range in price from \$0.003

to \$0.007 per square foot per mil (dry film) and are similar to solution acrylics in that crosslinkable grades are available and a drying cycle is also required.

UV screening agents are not as easily incorporated into emulsion polymers because of the difficulty in dispersing additives in a two-phase system (water and polymer). Whether solid-, solvent-, or latex-based, acrylic coatings should be primarily methacrylate-based for maximum durability; and have high tensile strength and possess ultimate elongations of 15-20 percent for optimum toughness.

As adhesives (Table 3-13), the second-generation acrylics are the compounds of choice. Cyanoacrylates are prohibitively expensive at approximately \$0.30/ft²/mil; solvent-based compounds require drying times and heat cycles to cure; and first-generation acrylics have long set times. The second-generation materials are fairly inexpensive (\$0.008/ft²/mil), are easily applied, require no preparation, and have high bond strengths with short cure times.

To function as a potting compound, a compound must be transparent and processable but must also possess low modulus in order to provide the necessary stress relief from thermal excursions. To date, no commercially available acrylic compound has been found that entirely satisfies this need. Pourable thermoset formulas exist (Table 3-9), but they are very high in modulus and are too expensive to be of any use. Hot-melt adhesives (Table 3-13B) are processable at sufficiently low temperatures and are soft enough to provide stress relief, but they are often hazy and do not thermoset to a rubbery or resilient compound. Modification of hot-melt acrylic formulas, such as Rohm & Haas QR-667 hot-melt adhesive, is the most promising direction in which to go towards a successful low-cost and durable potting compound.

Springborn Laboratories has demonstrated the possibility of developing pourable, transparent, thermoset acrylic potting compounds from low-cost readily available monomers. These polymers have similar handling

characteristics to Sylgard 184, a low-viscosity fluid that can be poured into a mold and cured to a low-modulus elastomer at either room temperature or an oven cycle. Current laboratory approaches are based on dissolving a very low molecular weight butyl acrylate/methyl acrylate copolymer in diethylene glycol dimethacrylate (Rohm & Haas Monomer X-970). Polymerization is accomplished with an appropriately selected peroxide and an amine or metal complex activator. These compounds are strictly experimental at this time and their utility remains to be proven.

SUBSTRATE SURVEY

Nine basic design options have been considered for the construction of flat-plate style modules. Of these options, two primary types can be noted: superstrate bonded and substrate bonded. Both superstrates and substrates are defined as the load-bearing components of the module and the part to which the cells are (adhesively) bonded. Superstrates ride above the cells and must obviously have high optical transparency; substrates carry the cells from the underside and may be opaque.

From a comparative cost analysis of candidate materials it became apparent that this construction element would command the highest proportion of the 1986 raw materials cost allocation; a discussion follows.

In this study (ongoing), various substrates and superstrates were considered in four basic classes: metals, ceramics, plastics, and wood/agricultural materials. In order to create a comparative study, it was necessary to generate a uniform costing procedure so that all candidates can be compared on an equal cost/performance basis. To do this, calculations based on a currently used module design (Solar Power Corporation) have been employed. The collector consists of a flat-plate substrate 45 inches in length by 15 inches in width, with cells adhesively bonded to it, and an overlay of low-modulus pottant. Under the current JPL specification, the panels must be able to withstand uniform wind loadings

of 50 pounds per square foot without flexing to the point at which cell fracture, inter-connect damage, delamination, or other failure occurs.

For a panel of the dimensions given, the center-point deflection should not exceed 0.25-inch; and on the basis of this specification, it is possible to calculate the required thickness, modulus, and cost of potential substrate materials. The calculations are made using the following assumptions:

1. Superstrate (or substrate) is supported around the entire perimeter by a metal frame and elastomer channel.
2. The frame is infinitely rigid.
3. The panel is rectangular - 45" x 15" (1.14 m x 0.38 m).
4. The pottant and solar cells carry no load.
5. The maximum wind load is 50 lb/ft² normal to panel from front or back.
6. The maximum deflection of the panel at the center is 0.25-inch (approximately the minimum breaking limit for 4-inch diameter cells).

Working from these assumptions, equations describing the deflection characteristics under uniform loading for flat plates have been published^(a) and are described as follows:

$$(1) \quad t \text{ (stress at center)} = \frac{\beta q b^2}{t^2}, \text{ psi}$$

and

$$(2) \quad y \text{ (deflection at center)} = \frac{-\alpha q b^4}{E t^3}, \text{ inches}$$

where q = uniform loading, psi

t = thickness, inches

E = modulus of elasticity, psi

b = width

a = length

and α and β = constants derived from the ratio, a/b

(a) Roark - Formulas for Stress and Strain; McGraw-Hill Publishing Company.

For this particular exercise, the uniform loading, q , is equal to 50 lb/ft² or 0.347 psi; a and b are, respectively, 45 inches and 15 inches; α and β are, respectively, 0.1335 and 0.7134 inches; and y is equal to the maximum center-point deflection specification of 0.25-inch. In all cases the calculated center stress from equation (1) was substantially less than the materials' tensile strength, indicating that the flat plates would not themselves crack under the deflection conditions specified.

By rearranging equation (2), the product of thickness and flexural modulus may be expressed as:

$$Et^3 = \frac{-\alpha qb^4}{y}$$

and by substituting with the following given values:

$$Et^3 = 9380 \text{ lb-in.}, \text{ or}$$

$$t^3 = \frac{9380}{E}$$

Therefore, the minimum required thickness for any load-bearing panel (substrate or superstrate), given the design specified, is equal to the cube root of 9380 pound-inch divided by the flexural modulus in pounds per square inch.

From the flexural modulus, cost per pound, and density, it then becomes possible to calculate the minimum required thickness and weight per square foot. Simple multiplication of the weight by the cost per pound

then equals the minimum required cost, which serves as the basis for substrate material comparison.

Tables 3-14 through 3-17 list the superstrate and substrate materials surveyed to date, along with their cost and modulus data, and the calculated thickness required for each. The last column is the cost for a flat plate of each material of the required thickness.

As the tables indicate, the study was divided into sections according to the class of materials under investigation. For some composites, flexural modulus values could not be found since the value changes with variations in design.

A brief survey of transparent load-bearing materials rapidly establishes that the least expensive material capable of functioning as a superstrate is glass - at a cost of \$0.29 to \$0.30 per square foot, at the required thickness (0.09-inch).

Acrylic polymers are also a logical choice because of their relatively low cost, inherent weatherability, and ease of fabrication. The required thickness to withstand 50 psf wind loading is found to be 0.315-inch, however, which calculates out to a cost of \$1.77 per square foot. Polycarbonate is even more expensive at \$3.41 per square foot at a thickness of 0.308-inch, and is much less weatherable than either of the other two materials.

A more intensive survey was continued towards the selection of candidate substrates.

Plastic materials were the first considered - because of their fabrication versatility, relatively low cost, high availability, and the possibility of their being compounded with inexpensive fillers to further reduce the cost.

The cost effectiveness is basically a ratio of the stiffness (flex modulus) to the material cost. Fillers and fibers added to improve the rigidity also raise the density, however, and consequently many of the

high-strength materials are less cost effective because of the increase in cost per unit volume. The uniform costing procedure previously described is the only efficient method of evaluating the candidates.

Costs per square foot of module at the calculated thickness appear in the last column of each table.

Resin-reinforced structural laminates such as epoxy and polyester preimpregnated glass matt were all extremely expensive, ranging from about \$2 to \$4 per square foot, except for a paper-based phenolic laminate at \$1.28 per square foot. Unfilled homopolymers and copolymers ranged from \$3.41 per square foot for polycarbonate to \$0.725 per square foot for polystyrene to a low of \$0.53 per square foot for styrene-maleic anhydride copolymer - one of the least expensive compounds yet found.

It was assumed that the stiffness-to-weight ratio of structural foam plastics would place them at an economic advantage, but actual costing found them to be competitively priced with many filled resins. Foamed plastics priced out at \$0.66 per square foot (Dylark; foamed styrene-maleic anhydride) to approximately \$1 per square foot for polypropylene foam.

The least expensive plastics found to date fall in the 50-60 cents per square foot range - the best being polypropylene with 40 percent talc filler, at \$0.518 per square foot.

A brief survey of some of the more widely used metal construction products (Table 3-15) indicates that they may be competitive with plastics. Galvanized steel priced out at \$0.56 per square foot for the thickness required, and hot-rolled mild steel at \$0.421 per square foot. Aluminum, desirable for its weathering resistance costs \$1.11 at the required 0.098-inch thickness. It should be noted that these prices are derived from commercially available forms, and gages of the required thickness may not currently exist.

The use of metals may also incur an additional fabrication cost if special design is required, as opposed to plastics that may be molded in a one-step operation.

Ceramic-based substrates were also briefly considered (Table 3-16), and costed out at lower prices than either plastics or metals. A drawback, however, is that the densities of these materials are so high, that they would undoubtedly require expensive support. Glass reinforced gypsum board in 1-inch thickness is capable of sustaining the 50 lb/ft² wind loading according to the manufacturer, and costs approximately \$0.30 per square foot. Although the price is attractive, this type of substrate would not endure outdoor weathering for long because of its high water sensitivity. The cost of upgrading would probably be high. Additionally, the elastic limit in this and other ceramic materials is very low. Small deflections in the panel would cause cracking and fatigue, leading to catastrophic failure.

Elasticized cement is a weatherable compound, however, and has a degree of flexibility not found in other mineral products. Latex-modified cement is estimated at \$0.40 to \$0.50 per square foot in 1/4-inch thicknesses. The load-bearing capacity is not presently known, and the cost also needs further investigation.

Table 3-17 lists some of the wood product substrates investigated to date. This class represents the lowest cost structural materials yet found that are available for solar module manufacture without extensive research and development effort. Conventional 1/2-inch sanded plywood (Potlatch Company) prices out, at the required thickness of 0.21-inch, at \$0.126 per square foot. Translated to a standard 1/4-inch thickness, the cost becomes \$0.151 per square foot. This is approximately three to four times less than the cost of the least expensive plastic compounds surveyed.

A disadvantage to plywood, however, is that it is manufactured in only certain standard thicknesses and would require retooling to produce

special grades. This difficulty is overcome with the use of particle boards such as hardboard, chip board, and flake board - all of which are made by an extrusion and/or compression-molding type of process in which the thickness may be varied.

The lowest-cost particle board discovered so far is a 3/8-inch thick wood chip/phenolic binder composite (Roadman Company) which is marketed as having a flexural modulus of 500,000 psi and a cost of \$0.16 per square foot. Calculation of the cost based on the thickness required by the wind deflection equation (0.265 inch) comes out to be \$0.11 per square foot (44 percent of the 1986 raw materials allocation). Unfortunately, this product is not weatherable in its commercial form.

As may be seen in Table 3-17, the other types of fiber or particle board are similarly priced. The results of the wood products survey are highly encouraging, and continuation into a more extensive survey is recommended.

Paper based materials are only just coming under investigation and three products of interest have been identified. A structural paneling material known as "Homasote" is available in 0.5-inch thickness at \$0.14 per square foot. This compound is prepared from waste paper and has a flexural modulus of 80,000 psi, which provides adequate deflection resistance for its thickness. Another interesting product is a weather-proofed pressed paper-board panel manufactured by Mead Paper-board Products, Inc. under the trade name of "Pan-L" board. This panel material has a modulus of 615,000 psi and requires 0.24-inch thickness for adequate wind resistance at an estimated cost of \$0.24. Mead claims this panel board has endured 17 years of outdoor weathering in Wisconsin. Lastly, preliminary contacts have been made with Hexcel Corporation, manufacturers of a Kraft paper honeycomb-composite structural panel costing approximately \$0.09 per square foot. This product is made for internal or protected use only, however, weatherable grades are currently

under development. The equipment flexural modulus or load-bearing capacity of this material is not known at this time, but the low cost and high strength warrant further investigation.



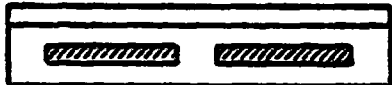
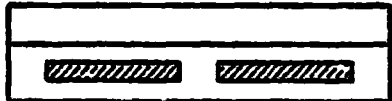



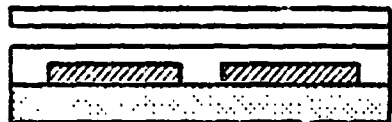
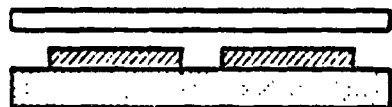
Weatherability is also a factor requiring consideration. One side of the substrate will be covered with cells and pottant, presumably supplying adequate protection; but the underside may require a specialized treatment or coating. Wood products again have importance in this area due to the advantages presented by:

- . History of actual outdoor aging in a wide variety of climates
- . Known preservation techniques (such as Koppers "Osmose K-33")
- . A known technology of protective marine paints and coatings
- . The ability to formulate binders for maximum hydrolytic and adhesive stability

There are many well documented methods for stabilizing plastics, also (incorporation of zinc oxide or carbon black); however, there is no cost margin remaining to upgrade these materials if they already exceed the cost allocation.

In consideration of the extent of this survey and without the pursuit of innovative designs to maximize the strength-to-weight ratios, wood and paper products stand out as the most viable candidates for the 1986 encapsulation goals.

FIGURE 3-1
Flat-Plate Solar Module Design

Design	No.	Description
	1.	Cells bonded to rigid substrate; transparent encapsulant, top cover.
	2.	Cells bonded to underside of transparent superstrate/top cover; encapsulant; back cover.
	3.	Rigid single transparent encapsulant; top cover.
	4.	Flexible single transparent encapsulant; rigid clear superstrate.
	5.	Flexible single transparent encapsulant; rigid substrate.
	6.	Cells bonded to rigid substrate; clear conformal top coat.
	7.	Cells bonded to clear superstrate/top cover; conformal under coat.
	8.	Cells bonded to rigid substrate; clear encapsulant; air gap; top cover.
	9.	Cells bonded to rigid substrate; air gap; top cover.

4. EXPERIMENTAL ACTIVITIES

This section covers the experimental activities of the last year and investigations into four subject areas:

- UV Upgrading

In this study plastics were compounded with additives or coated with ultraviolet absorbing coatings to increase the resistance to degradation. Specimens were evaluated and compared to unstabilized controls after exposure to Weather-Ometer and fluorescent sunlamp conditions. Internal compounding provided some improvement in properties, especially retention of optical transmission. The performance of cellulose-acetate-butyrate (CAB) was dramatically improved, no disintegration occurring.

Films and coatings proved to be generally more efficient, the best being Tedlar-UT film (du Pont). Acrylic coatings containing dissolved UV absorbers were found to greatly increase the lifetime of easily degraded polypropylene and may provide an inexpensive and replenishable method to protect solar module components.

- Plasma Spray Coating

The technique was investigated as a method for applying pottant materials since it offered the potential for cost-effective and rapid automated module fabrication. Experimental attempts were unfortunately unsuccessful due to fracturing of cells from high heat build-up. The process is also limited to high-modulus materials that may be finely ground, whereas soft elastomeric compounds are the most desirable pottants.

- Module Fabrication

Four sets of four modules were fabricated for the April PIM meeting. Techniques were developed for applying the pottant to the cell and substrate arrays. A UV-stabilized acrylic film was then bonded as an outer cover on the pottant to provide increased environmental resistance.

The modules were put through the humidity and temperature cycling tests at JPL.

The pottant/substrate combinations w^h for these modules were:

- . PVC plastisol/flakeboard (substrate)
- . EVA/galvanized steel
- . Ionomer/rigid PVC
- . Acrylic/phenolic

Four other single modules were also fabricated using:

- . EPDM/styrene honeycomb
- . Flexible polyester/plywood
- . Crosslinked acrylic/Masonite
- . Aliphatic urethane/styrene-maleic anhydride sheet

• Weathering Studies

The physical and optical performance of various polymers have been assessed and compared after exposure to a variety of weathering conditions. The environments included outdoor exposures, EMMAQUA, Weather-O-Meter and fluorescent sunlamp. To date the Plexiglas acrylic compounds and the fluorocarbons have the best property retention.

There follows a detailed discussion of these investigations.

UV UPGRADE

Only acrylics, silicones, and fluorocarbons are inherently resistant to weathering. This limitation does not mean that plastics cannot be modified for outdoor use, however. Weather-resistant coatings or internal compounding of special additives can achieve dramatic improvements in environmental resistance.

The deterioration of plastics in outdoor weathering is caused primarily by sunlight - especially ultraviolet - frequently combined with atmospheric oxygen and often involving moisture, abrasion, and other factors as well. Sunlight reaching the earth is filtered through the atmosphere, removing shorter wavelengths up to 290 m μ before it reaches the surface of the earth. Thus ultraviolet effects on plastics result primarily from wavelengths of approximately 290-400 m μ , which is approximately 5 percent of the total solar radiation reaching the earth.

In general, ultraviolet energy initiates breakdown by dissociating a covalent chemical bond into a free radical. This initiates a free-radical chain reaction. In the presence of atmospheric oxygen, this usually becomes an oxidative chain reaction. Formation of degradation products like C = O and C = C double bonds, and hydroxyl O - H and peroxide O - O groups increases the number of groups which can absorb ultraviolet light and thus accelerates the degradation reaction.

Deterioration by weathering will depend on the material, the additives, the total amount of radiation absorbed, the temperature, humidity, and possibly other factors.

These chemical modifications of the polymer are responsible for the deterioration of optical and mechanical properties and usually result in reductions of tensile strength, elongation, and transparency.

Protection from UV light is obtained with stabilizers known as ultraviolet absorbers and quenchers; protection from oxidation is achieved with the use of antioxidants. Most frequently the two used together have a synergistic reaction in which the increase in weatherability is greater than that obtained with the use of either one alone. Antioxidants used

alone - especially in large quantities - often accelerate UV-catalyzed degradation.

The most efficient form of stabilization involves the use of pigments which render the polymer opaque. Generally, the most effective means of improving the weather resistance of plastics is to compound them with carbon black. Carbon black is totally opaque to both visible and ultra-violet portions of the spectrum and additionally serves as a highly effective free-radical trap that inhibits chain scission. Zinc oxide is another efficient UV-absorbing opaque pigment that is white in color and consequently heat and light reflective. Although the primary interest in LSA at present is transparent coating and potting compounds, the use of opaque additives will probably find application in the stabilization of substrate and undercoating materials.

Transparent materials are much more difficult to stabilize, requiring either appropriately selected overcoatings and/or the correct blend of UV absorbers, antioxidants, and other stabilizers. Tables 4-1 and 4-2 list various common commercial UV stabilizers and antioxidants that may be useful for this purpose. UV stabilizers are typically used at 0.2-0.8 parts per hundred parts resin, and antioxidants at the 0.05 to 0.5 parts level.

A study was conducted on improving the performance of polymers selected from the original materials program and to determine the feasibility of upgrading them. The materials selected were Lexan 123, Tenite 479 (cellulose acetate butyrate), C-4 polycarbonate, and the two acrylics - Plexiglas DR-61K and Plexiglas V-811. These plastics were chosen before the more extensive surveys were conducted, and although they will not be recommended for module construction, they serve to demonstrate a concept and technology that may be applied to other compounds at a later time.

Two basic approaches were employed to increase the ultraviolet stability of these polymers: internal compounding and external coating.

Compounding was performed on a two-roll mill - permitting the incorporation of other substances into the polymer at its melt temperature. Generally, four types of stabilizers are added to maximize degradation resistance:

- (1) Absorbers - compounds that absorb ultraviolet light strongly and preferentially, and convert the energy to harmless fluorescence or heat.
- (2) Quenchers - compounds that interchange energies with excited polymer molecules and return them to ground state before bond scission occurs.
- (3) Metal deactivators - chelating compounds that destroy the effect of trace metals that catalyze oxidation of the polymer molecule.
- (4) Antioxidants - compounds that interrupt free-radical chain-reaction mechanisms or decompose peroxides that give rise to bond scissioning and depolymerization

A list of compounds typically used for these functions appears in Tables 4-1 and 4-1. Each of the five materials previously mentioned was compounded with formulas A, B, and C - as follows:

<u>Stabilizer</u>	<u>Function</u>	<u>Formula (phr) *</u>		
		<u>A</u>	<u>B</u>	<u>C</u>
Cyasorb UV-531	Absorber	0.5	-	-
Cyasorb UV-1084	Quencher	0.3	0.3	-
Tinuvin P	Absorber	-	-	0.5
Uvinul N-539	Absorber	-	0.5	-
Polygard	Metal deactivator	0.3	0.3	0.3
AM-105	Quencher	-	-	0.3
DSTDP	Antioxidant	0.3	0.3	0.3
Irganox 1010	Antioxidant	0.2	0.2	0.2

* phr = per hundred parts resin

In three cases, already upgraded materials were obtained from the resin manufacturers and substituted for the preceding formulas. Lexan 123 - Formula C - was replaced with Lexan 9030; Tenite 479 - Formula B -

with Tenite 485; and Plexiglas V-811 - Formula B - was replaced with Grade UVA-5.

In most cases the compounding operation imparted a slight yellow color to the polymers, resulting in losses of 5-10 percent total optical transmission (Table 4-5 - controls).

The upgraded materials were compared to their unstabilized equivalents after 120 days of exposure to the carbon arc Weather-Ometer and RS-4/55°C conditions. Plexiglas V-811 and cellulose acetate butyrate formulas were continued to 240 days of exposure. Measurements were made of hardness, visible optical transmission, ultraviolet optical transmission (Tables 4-3, 4-4, and 4-5); and for mechanical properties: yield strength, tensile modulus, ultimate elongation, and tensile strength at break (Tables 4-6 through 4-9, respectively).

Variations in surface hardness (Table 4-3) between aged and unaged specimens were not particularly large nor did they demonstrate correlation with other properties. Improvements in the retention of optical transparency were found in almost all cases (Table 4-5), the increase ranging from 5 percent to 20 percent of control.

Plexiglas V-811 demonstrated an optical improvement of 5-8 percent over the control with a proprietary formula (UVA-5). The other acrylic, Plexiglas DR-61, showed a similar increase of 6-7 percent with upgrade Formula C. Formula C was also successful in C-4 polycarbonate resin, raising the 120-day Weather-Ometer transmission by 20 percent over the control value.

Measurements of total ultraviolet transmissions (Table 4-4) were found to retain their zero value for all upgraded compounds after 120 and 240 days of exposure.

Improvements in mechanical test results were not as encouraging.

The most notable improvement in physical properties occurred in the case of Tenite 479 - cellulose acetate butyrate. Specimens remained in good shape and were tested after the 120-day exposure, whereas previously the polymer had flowed to the point of destruction.

The manufacturer's upgraded compound, 485, was superior for the initial 120 days, retaining tensile strength in excess of 3000 psi and elongation of approximately 20 percent; but the Springborn Laboratories Formula A performed more successfully over a longer time. Formula A in cellulose acetate butyrate maintained an 86 percent optical transmission after 240 days of exposure to RS-4 sunlamp and 40 percent of its original tensile strength. Although the elongation dropped badly, all other cellulosic specimens disintegrated.

Yield strengths and modulus values varied little in most compounds and revealed no particular information on increased stability. Elongation values suffered in the process of compounding prior to exposure - except for Plexiglas DR-61, which doubled to 35 percent.

Losses in the four other materials ranged from 50-90 percent, both before and after aging. The two acrylics, Plexiglas V-811 and Plexiglas DR-61, were the least affected, but these materials have low elongations to begin with. Tensile strength measurements, Table 4-9, were slightly lower after compounding and exposure, but showed no dramatic changes.

Except for marginal increases in optical transmission and elongation, the performance of Plexiglas V-811 does not appear to be substantially improved by the incorporation of UV absorbers, quenchers, and antioxidants.

This task appears to have been successful in improving the properties of Tenite 479 cellulosic and imparting more optical stability to the other plastics; however, the loss in elongation values is disturbing.

The raw material add-on cost for the incorporation of additives is about \$0.04 - \$0.06 per pound of polymer.

Two materials, Plexiglas V-811 and Tenite 479, were selected for further upgrading studies involving coatings based on three approaches:

- (1) Tedlar film - 100 BG30 UT (ultraviolet opaque).
- (2) Acrylic coating: Acryloid B-82 containing 4 percent Cyasorb UV-1084 and 4 percent Cyasorb UV-531.

- (3) Photochemical rearrangement: solution of poly(resorcinylic isophthalate). Ultraviolet opacity is induced by UV, causing the polymer to undergo Fries rearrangement.

Only the first two ideas were successful. The last approach (3) gave a nonadherent film which came off the test specimens easily, leaving them unprotected.

Tedlar 100 BG30 UT gave adequate protection to the Plexiglas V-811 but failed when used over Tenite 479 cellulosic. After RS-4 exposure (240 days) the specimens were too brittle to test and broke upon handling. Internal compounding is a much better method of providing protection for this material. Plexiglas V-811 coated with Tedlar survived with much higher elongation and tensile strength values than with compounded formulas, but only in RS-4 conditions. Weather-Ometer stability appears to have improved more from compounding (compare tables 4-9 and 4-10). Optical transmissions remained very high (85-93 percent) for both materials protected by Tedlar (Table 4-12).

Exposures of UV-Acryloid coated specimens for 240 days showed the Plexiglas to perform quite well (about the same as Tedlar); but the cellulosic disintegrated (Table 4-11). Degradation in cellulose acetate butyrate also appears to be water sensitive, the properties decreasing more rapidly in the Weather-Ometer than under RS-4 exposure. The UV-Acryloid film is water vapor transmissive in thin sections and may not have served as an efficient barrier, contributing to the faster decomposition of this compound.

Stabilizing films and coatings were investigated further. Upon surveying present commercial sources, very few transparent UV-absorbing films were discovered. Acrylic or fluorocarbon films have been laminated commercially over thermoplastic sheet materials, with notable increases in weatherability. Korad acrylic film (Excel Corporation, Newark, New Jersey) is an example of this approach.

Only three domestic commercial ultraviolet-absorbing films were discovered: Tedlar UT (du Pont, Wilmington, Delaware), Llumar (Martin

Processing, Martinsburg, West Virginia), and a plasticized polyvinyl butyral - Saflex UV-40 (Monsanto Chemical Company, Springfield, Massachusetts). Saflex UV-40 is a sheet resin employed in laminating architectural safety glass. The ultraviolet screening agent serves to protect the colors of rugs, fabrics, paintings, etc., behind shopfront windows. It is designed for and restricted to use as a glass laminating material. The other two films - Tedlar UT (0.001 inch) and Llumar (0.005 inch) - cost \$0.046 and \$0.22 per square foot, respectively, or 20 and 95 percent of the 1986 materials cost allocation for the encapsulation task. The Llumar film can obviously not be used; and the Tedlar is still expensive at one-fifth of the total allocation.

Experiments were conducted to determine the feasibility of preparing low-cost, UV-absorbant coatings. Solution acrylic coatings were chosen as the vehicle (Acryloid series; Rohm & Haas Company) due to their low cost, transparency, and inherently excellent weathering characteristics. Three UV absorbers chosen from the benzophenone and benzotriazole classes of UV stabilizers (Table 4-1) were blended into each of the formulations shown in Table 4-13 at two concentrations. Films were subsequently cast and dried to a thickness of 0.001 inch. The 2 and 5 phr concentrations were chosen based on Springborn Laboratories experience; the 5 and 10 phr levels used for Permasorb MA were based on recommendations by National Starch.

Transmittance measurements show these films to be approximately 80 percent transmissive in the visible regions, and from zero to 11 percent transmissive in the ultraviolet range (Table 4-13). Four formulations had no transmittance at all in the UV region, and these ranged from \$0.0092 to \$0.0122 per square foot per mil. This corresponds to approximately 20 percent of the cost of Tedlar or 5 percent of the materials cost allocation. Increase in additive level of the UV stabilizer does not always result in a significant decrease in UV transmission. This may occur because the UV transmission is already low, even at the lower additive concentration. Extensive effort is required to optimize the UV additive system with regard to type and concentration of UV

stabilizer(s) and presence of synergists. Optimum systems will also vary with the polymer vehicle.

The ultimate efficiency of these coatings in protecting an underlying pottant is not known at this time, but experiments have been conducted to generate comparative data on the degree of protection offered by these coatings versus Tedlar-coated and uncoated control specimens of polypropylene, a plastic very easily damaged by UV radiation.

Compression-molded bars (3-1/2" x 1/2" x 20 mils) were prepared of polypropylene (Profax 6523, Hercules Powder Company) and coated with 1-mil layers of Formulations A6693-4, -5, -10, and -12 (Table 4-13) and Tedlar 100 BG30 UT, and exposed to accelerated aging in the RS-4 fluorescent sunlamp chamber.

After sixteen weeks (2700 hours), the least damaged specimens were those protected by UV-absorbing Tedlar. These specimens did embrittle and crack in some areas but generally retained flexibility in over about 60 percent of their areas. The best UV-Acryloid solution coated bars were flexible over about 40 percent of their areas, and degradation was obvious over the remainder of the specimen.

The areas retaining flexibility all demonstrated good localized adhesion of the coating and damaged areas all had cracked and delaminated coatings. This suggests that loss of adhesion was the major factor contributing to the failure of the specimens.

The most efficient formula (A6693-4) consisted of 5 parts of Tinuvin-P (on a solids basis) dissolved in Acryloid B-44. Specimens with less efficient coatings generally crumbled under stress. All uncoated controls turned to coarse powder after two weeks of exposure.

It is felt that the UV-Acryloid coatings may be equally as efficient in providing protection as the Tedlar, provided that the adhesion and elongation (to prevent stress cracking) can be improved.

In conclusion, the feasibility of protecting a UV-sensitive polymer by internally compounded stabilizers or by absorbing coatings has been demonstrated. The next step is to reformulate additives and protective coatings to optimize the environmental resistance of polymers

to be used in module construction to give the longest possible life.
Marginally weatherable but otherwise cost effective plastics may also
become viable candidates by these methods.

PLASMA SPRAY PROCESS

The plasma spray process was selected for investigation because of the potential for high-speed automatic array processing. Of the many possible coating techniques, plasma spray is unique in permitting conformal coatings of pure solvent-free polymers to be deposited with no vehicle other than an inert gas stream.

Plasma spray systems have been used for many years in the past to deposit high-temperature materials such as nickel, chromium, glass, aluminum oxide, and other refractories onto a variety of substrates. As a result of recent process and equipment innovations by Sealectro Corporation in Mamaroneck, New York, this method is now applicable to a wide range of plastic materials - including both thermosets and thermoplastics. Due to the speed and relative ease of this technique, experiments were conducted to determine the suitability of this approach for the coating/encapsulation of solar modules and the potential for automated production.

The basic principles of plasma spray technology are relatively simple. Nitrogen, an inert and inexpensive gas, is ionized between a set of coaxial electrodes and passes out of the spray nozzle as a high-velocity, high-temperature plasma jet. The dry, powdered polymer is blown onto the surface of this hot jet by another stream of nitrogen, where it melts. High-velocity molten plastic particles then impinge on the target substrate, where they coalesce into a continuous, integral, adhering film. The heat range required for the polymer may be varied by changing the position at which the polymer powder enters the plasma jet. Heat-sensitive plastics are injected onto the cooler (200-300°F) peripheral surface of the jet.

The physical characteristics and quality of the deposited film depend on the (chemistry of the) coating powder and also on the nature and surface preparation of the substrate. Although nothing more than a clean surface is required for most applications, some treatment such as etching can improve adhesion.

Sealelectro Corporation's plasma spray system has demonstrated effective spraying of low- and high-melting thermosetting and thermoplastic powder coatings. These include epoxies, acrylics, polyesters, polyethylenes, polyurethanes, nylons, vinyls, cellulose, and fluoropolymers. An additional advantage of this process is that B-staged thermoset materials may often be cured directly in place, using the heat of the plasma jet, without subsequent oven postcuring.

Particle size distribution of the fluidized powder depends on the melting range and heat conductivity of the polymer - but generally falls in the range of 75-150 microns (100-200 U.S. Standard Mesh).

It is also important to note that the electrodes are not sacrificial and no metallic contamination of the coating material occurs that could decrease the insulation resistance or promote degradation.

The powder required to maintain and operate a single plasma jet with a resin throughput of approximately 40 pounds per hour is 8-12 KW at a nitrogen flow rate of 100-150 cubic feet per hour. These figures indicate a cost saving alternative to existing powder-coating techniques. Figure 4-1 compares the energy requirements for a model system of applying a thermoset epoxy coating to steel and ceramic substrates by the plasma spray and the fluid-bed processes. The plasma spray process can be seen to use only 20 percent of the thermal energy of the conventional technique.

The coating rate is dependent upon the melt viscosity of the polymer, but typically runs 100-200 square feet per hour for a single gun of current design (0.02-inch coating).

Two encapsulations were attempted using the plasma spray technique. Systems 1 and 2 using Halar 500 and Tenite 479, respectively, have been plasma sprayed over cells glued to a polyester substrate. System 1 proved to be completely unsuccessful, and the following observations were made:

- (a) Cells fractured in 100 percent of the modules attempted (9).
- (b) Melting of metalization could be noticed on all modules, even though a thin coat of polymer was applied.

- (c) "Shadowing" around interconnects and cell edges where the spray did not reach was apparent.
- (d) Loss of adhesion and delamination of the Halar film occurred in small areas over the cell surface.
- (e) It is believed that the silicon wafers were exposed to more thermal shock than expected, partly due to the poor transfer of the polyester substrate.

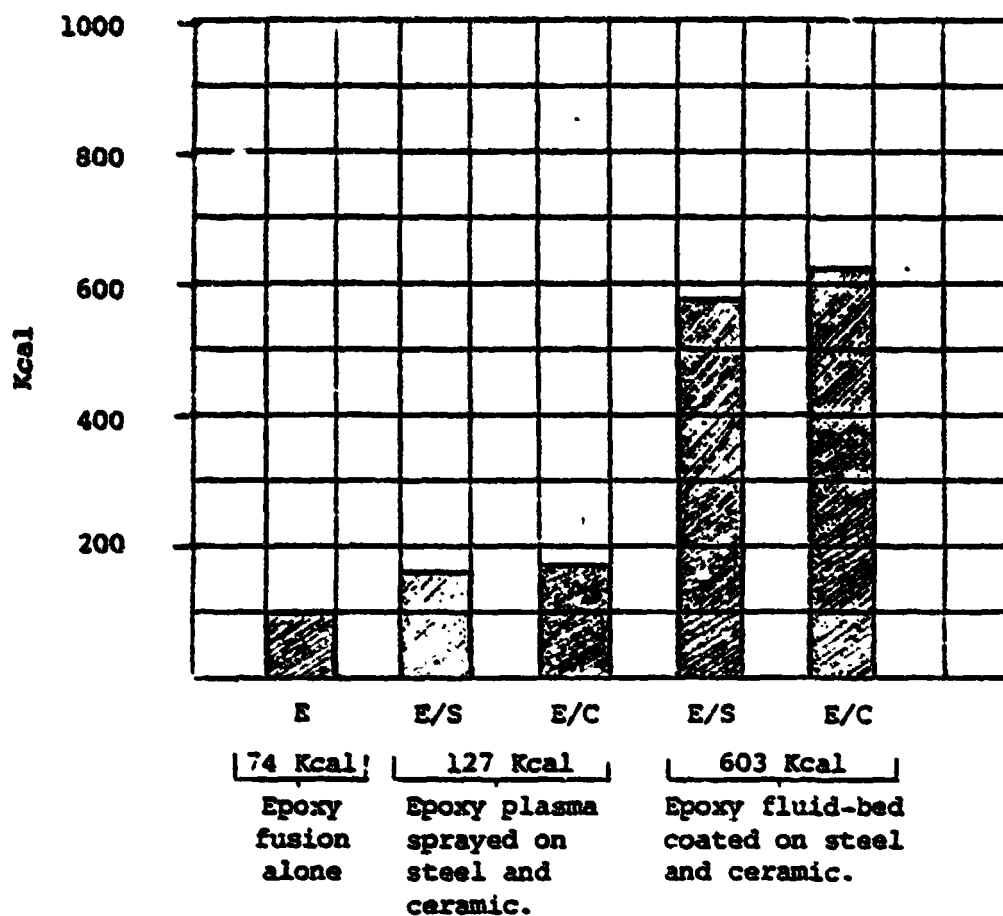
In System 2, Tenite 479 (cellulose acetate butyrate), there was but one fractured cell among the twelve modules coated. Despite the low melting point of CAB (150°C), enough heat buildup occurred to cause some localized melting of the solder on some modules. The CAB layer deposited was very transparent, still showed some signs of shadowing (nonconformality), and had a slightly rippled surface. One difficulty with this material is that it still may not have sufficiently low modulus to provide the required degree of stress relief from thermal expansion.

A limitation of the plasma spray process is that only high-modulus (and therefore friable) plastics may be used. Soft, rubbery materials - most useful as potting - cannot be applied by this method.

Although the use of plasma spray has not been successful for this phase of the encapsulation task, it may provide an economical way to apply coatings in various other areas of the LSA project.

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FIGURE 4-1
Energy Comparison



Average energy difference: $\frac{476 \text{ Kcal}}{1883 \text{ Btu}} = 20\%$

Support Data for Figure 4-1

Material Constants	Epoxy	Steel	Ceramic
Size (ft ² xin.)	100 x 5 mils	100 x 1/4	100 x 1/4
Density (g/cm ³)	1.5	7.83	3.32
Weight (Kg)	1.77	28.2	11.95
Specific heat (cal/g)	0.25	0.11	0.27
Melting point (°C)	190	-	-
Δ T (Temperature Difference)	167	167	167
ΣΔH (Total Heat) (Btu)	293	2056	2138
ΣΔH (Total Heat) (Kcal)	74	518	539

MODULE FABRICATION

In order to establish a base of real experience with candidate construction materials identified in the surveys, a series of miniaturized solar modules were constructed for the April 1978 Project Integration Meeting. In this study, encapsulation processes were investigated and described, real cost analyses were performed, and problem areas were elucidated.

Each module consisted of a 12" x 12" substrate carrying nine regularly spaced solar cells of 90 mm diameter. Three discreet electrical circuits were established using plated metal interconnects (Lockheed type) between the cells and soldered to feed-through connectors so that electrical connection could be made on the underside of the module. Potants were then used to fully encapsulate the cells by a method most suited to that particular material. The last step involved coating the module with UV-absorbing acrylic film to protect the underlying compounds.

Four major systems were developed, built in quintuplicate, and submitted to Jet Propulsion Laboratory for qualification testing. The potant/substrate combinations and our findings were briefly as follows.

I. PVC Plastisol/Flakeboard (Aspenite) System

This module consisted of a curable liquid polyvinyl chloride plastisol poured into place over cells supported on a flakeboard substrate. Subsequent application of heat caused the plastisol to fuse and become transparent in addition to curing to a creep-resistant gel.

An unforeseen problem with this formulation is that contact with water causes hazing and loss of transmission. This phenomenon is reversible and the pottant returns to initial clarity in dry conditions. Thermal cycling from -40°C to +90°C under JPL qualification testing was successful with no delamination of the pottant or damage to the cells occurring.

II. Ethylene-Vinyl Acetate/Galvanized Steel System

Three modules were fabricated by placing cells between two sheets of specially formulated ethylene-vinyl acetate copolymer supported by a primed

steel substrate. A subsequent heating cycle under vacuum caused the assembly to fuse and laminate into an integral unit. During air oven post-curing of the assembly some cure inhibition resulted in slight flow of the polymer. After exposing the modules to the JPL thermal cycling test some yellowing occurred, but no delamination or effect on I/V curve was detected. Some flow of the pottant in the vertical position was noticed.

III. Ionomer/Rigid PVC System

These modules were constructed by thermally fusing a layer of ionomer resin powder over adhesive-coated cells bonded to a rigid filled polyvinyl chloride substrate. The fusion was conducted in a vacuum oven and completed in a circulating-air oven. Thermal cycling was disastrous, giving rise to delamination between the pottant and substrate and resulting in cell fracture.

IV. Hot-Melt Acrylic/Phenolic Substrate System

These modules were prepared by melting (in vacuum) a layer of transparent hot-melt acrylic adhesive over cells mounted on a filled and cured phenolic board. These modules performed very poorly during thermal cycling due to excessive flow of the potting compound and destruction of the outer cover.

In addition, single modules of four other combinations were built to generate a basic familiarity with a variety of other materials. These modules were constructed for demonstration purposes and were not run through the JPL qualification test program.

• EPDM/Polystyrene Honeycomb (Norfield Corporation)

The open-celled honeycomb was faced with a thin rigid PVC film to support the cells prior to coating with a compounded ethylene propylene diene rubber. The system developed problems with warping, yellowing, and loss of adhesion of the various components.

- **Polyester/Plywood**

A commercial thermoset polyester was modified to create flexibility and cured over cells mounted on a plywood substrate. Thick sections of the polyester were found to crack during the cure cycle and also demonstrated poor adhesion to cell and substrate.

- **Crosslinked Acrylic/Masonite**

The previously used acrylic hot-melt adhesive was compounded with crosslinking additives by cold milling. A layer of this compound was then melted over the cell array mounted on a sanded piece of hardboard. The physical properties showed improvement in durability but the compound was still not sufficiently cured to prevent flow at 90°C.

- **Aliphatic Urethane/Styrene-Maleic Anhydride**

A two-part urethane was mixed, deaerated, and poured over a cell array mounted on a substrate of filled styrene-maleic anhydride copolymer. The assembly was then cured in a 100°C oven. Warping of the substrate was encountered under these conditions.

The following section provides a detailed description of each system, including the materials used, construction methods, and basic cost analysis.

Module I. - PVC Plastisol/Flakeboard

A. Materials of Construction

The following tabulation lists the various materials utilized in the construction of the PVC Plastisol/Flakeboard module.

<u>Material</u>	<u>Manufacturer</u>	<u>Nature</u>	<u>Bulk Cost, \$/Lb</u>
. Substrates			
Aspenite	Macmillan-Bloedel	Wood flake/phenolic binder (0.250 in.)	0.135/ft ²
. Cover Film			
Acryloid B48N	Rohm & Haas	Acrylic	1.18
. Pottant Materials			
Pliovic WO-1	Goodyear	PVC	0.39
Paraplex G-30	Rohm & Haas	Phthalate polyester plasticizer	0.67
Paraplex G-62	Rohm & Haas	Epoxidized soybean plasticizer	0.51
Monomer X-970	Rohm & Haas	Butylene glycol di-methacrylate	1.24
Thermolite 42	M&T Chemical	Tin stabilizer	3.43
t-Butyl perbenzoate	Lucidol-Pennwalt	Organic peroxide	2.05
. UV Absorbers			
Tinuvin P	Ciba-Geigy	Substituted benzo-triazole	9.25
Tinuvin 328	Ciba-Geigy	Substituted benzo-triazole	7.60
Tinuvin 770	Ciba-Geigy	Hindered amine	13.20

...Continued

<u>Material</u>	<u>Manufacturer</u>	<u>Nature</u>	<u>Bulk Cost, \$/Lb</u>
. Adhesive			
Pliobond 8004	Goodyear	Acrylic pressure-sensitive	0.73
. Adhesion Promoters			
A-174	Union Carbide	Vinyl silane	0.70
PFAZ-300	Ionac	Acrylic aziridine	3.95
. Sealer			
Cationic Emulsion 929	Dow Corning	Silicone latex	2.69

B. Module Assembly

. Material Preparation

1. Substrate and Constraining Walls

Aspenite flakeboard and strips of Douç'as fir were dried for 16 hours at 100°C. One surface of the flakeboard was sealed immediately prior to use; the other surface was sealed with Dow Corning 929 Cationic Silicone Emulsion. The strips were attached around the edge of the board with staples and Rohm & Haas (R&H) Rhoplex CA-12 acrylic emulsion as adhesive to yield a box-like structure to hold the pottant. The outside surfaces of the fir strips were sealed with R&H Acryloid B48N.

2. Pottant - PVC Plastisol

<u>Formulation:</u>	<u>phr</u>	<u>Ingredients</u>
	100.0	Goodyear Pliovic (PVC) WO-1
	67.5	R&H Paraplex G-30
	7.5	R&H Paraplex G-62
	25.0	R&H Monomer X-970
	2.0	M&T Thermolite 42 (stabilizer)
	1.011	Ciba-Geigy Tinuvin P (stabilizer)

After high-speed blending, the plastisol was vacuum-deaerated for 16 hours. A small amount of the PVC plastisol to be used as the initial substrate covering was blended with 2 percent of Ionac PFAZ-300, an aziridine adhesion promoter.

3. Cover Film - Acrylic, UV-Stabilized

Formulation:	phr	Ingredients
	222.0	R&H Acryloid B48N (45% in toluene)
	164.0	Toluene
	13.5	Butyl acetate
	2.0	Ciba-Geigy Tinuvin P UV stabilizer
	2.0	Ciba-Geigy Tinuvin 328 UV stabilizer
	2.0	Ciba-Geigy Tinuvin 770 UV stabilizer

The solution was cast on glass and dried to 1.5-2.0 mils thickness. A 2-mil film of Goodyear Pliobond 8004 acrylic pressure-sensitive adhesive was cast over the acrylic film. Just prior to use, the composite film was removed by immersion in water, followed by air drying.

4. Primer (Cell to Pottant)

Formulation:	phr	Ingredients
	6.0	Union Carbide A-174 vinyl silane
	94.0	Methanol

. Fabrication

1. Substrate Preparation

The sanded surface of the dry particle board was coated with 3 mils of the aziridine-modified PVC plastisol and the coating gelled by heating for 7 minutes in a 100°C oven.

The cell stringers were positioned in the gelled plastisol, and pin location and cell placement were marked. Holes were drilled for the terminal pins, which were cleaned with toluene and the heads tinned with rosin cone solder. The tinned pins were then coated lightly with epoxy

50 phr Miller Stephenson Epon 828/50 phr Miller Stephenson Versamid 125) and pressed into the drilled holes.

An aliquot of the PVC plastisol was then doctored over the substrate to a 20-mil thickness.

2. Cell Preparation

The three cell stringers were cleaned with methanol and toluene, treated with the vinyl silane (A-174) primer, and moisture-cured at 50 percent relative humidity.

3. Cell-to-Substrate Assembly

The stringers were pressed into the liquid PVC plastisol on the flakeboard and the interconnects were soldered to the terminal pins.

4. Final Module Lay-Up

More PVC plastisol was poured over the stringers to a total thickness of 93 mils and the assembly was deaerated under vacuum for 30 minutes.

The cover film with adhesive was applied over the uncured plastisol and rolled smooth with a glass rod. The edges of the film were folded under and bonded to the module.

The module was transferred to a 150°C oven for 45 minutes to fuse and crosslink the plasticol. This material is opaque in liquid form and becomes transparent as fusion occurs, giving a visual indication of completion.

C. Cost of Materials

The following tabulation presents construction costs, both present and projected, for the PVC Polastisol/Flakeboard module system:

<u>Material</u>	<u>Thickness (Mils)</u>	<u>Grams Used Per Ft²</u>	<u>Construction Costs (\$/Ft²)</u>	
			<u>Present</u>	<u>Projected, 1986</u>
. Cover Film				
UV-stabilized Acryloid B48N	2	5.2	0.02	0.2
. Adhesive				
Pliobond 8004	0.7	1.80	0.008	0.008
. Pottant				
Plastisol Formu- lation	93 (a) (35)	295 (75)	0.42	0.076
. Adhesion Promoters				
A-174 Silane	-	0.00127	Insignificant	Insignificant
PFAZ-300	-	0.176	0.0015	-
. Sealer				
Cationic Emulsion 929	-	10.8 (2)	0.064	0.012
Total, excluding substrate			0.514	0.115
Substrate - Aspenite Flakeboard	250	-	0.135	0.135
TOTAL			0.65	0.25

(a) Numbers in parentheses are 1986 projections.

Module II. - EVA/Galvanized Steel

A. Materials of Construction

The following tabulation lists the various materials utilized in the construction of the EVA/Galvanized Steel module.

<u>Material</u>	<u>Manufacturer</u>	<u>Nature</u>	<u>Bulk Cost, \$/Lb</u>
. Substrate			
Galvanized steel	Various	Galvanized steel - 0.062 inch	0.521 ft ²
. Cover Film			
Acryloid B48N	Rohm & Haas	Acrylic	1.18
. Pottant Materials			
t-Butyl perbenzoate	Lucidol-Pennwalt	Organic peroxide	2.05
Elvax 150	DuPont	Ethylene/vinyl acetate	0.55
. UV Absorbers			
Tinuvin P	Ciba-Geigy	Substituted benzotriazole	9.25
Tinuvin 328	Ciba-Geigy	Substituted benzotriazole	7.60
Tinuvin 770	Ciba-Geigy	Hindered amine	13.20
Cyasorb 531	American Cyanamid	Substituted benzo-triazole	4.80
. Antioxidant			
Irganox 1010	Ciba-Geigy	Hindered phenolic	5.35

...Continued

<u>Material</u>	<u>Manufacturer</u>	<u>Nature</u>	<u>Bulk Cost, \$/Lb</u>
. Adhesive			
Pliobond 8004	Goodyear	Acrylic, pressure-sensitive	0.73
. Adhesion Promoter			
Z-6032	Dow-Corning	Styrylamino silane	4.81

B. Module Assembly

. Materials Preparation

1. Substrate

Galvanized steel, 1/16 inch (0.157 cm), was cut to measure 12" x 12" (30.5 x 30.5 cm). The cut edges were sealed with epoxy and the coating was air dried for 1 hour at 50°C.

2. Wires

Polyethylene-coated wires were cut into 5-inch (12.7 cm) lengths; the ends were stripped and tinned with rosin core solder.

3. Pottant

The following charge was milled for 10 minutes at 46°C on a rubber mill:

<u>Parts by Weight</u>	
100.0	DuPont Elvax 150 (ethylene/vinyl acetate)
0.5	Lucidol t-butyl perbenzoate
0.15	Ciba-Geigy Irganox 1010
0.5	American Cyanamid UV-531

The milled stock was press-molded between Mylar sheets three times at 121°C to remove bubbles.

4. Primer (For Substrate)

Formulation:

Parts by Weight

10.0	Dow-Corning Z-6032 (50% solution)
0.05	Lucidol t-butyl perbenzoate
56.0	Reagent methanol

5. Edging

Ten-mil (0.025 cm) aluminum stock was bent to contain the molten Elvax pottant. The edging was taped to the bottom of the galvanized panel.

6. Cells

The wires were soldered to the cell interconnect extensions and cell stringers were cleaned with solvent.

7. Adhesive (Cell to Substrate and Pottant)

Formulation: 50 Goodyear Pliobond 8004 acrylic
 50 Reagent ethyl acetate

8. Cover

See PVC Plastisol/Flakeboard Module System I.

. Fabrication

1. Substrate Preparation

The galvanized panel was cleaned with a toluene and methanol wipe. The Z-6032 primer solution was swabbed on, was air-dried for 1/2 hour at 50 percent relative humidity and 23°C, and baked for 10 minutes at 90°C. The panel and Elvax pressing was cooled in a freezer.

The Mylar backing was peeled off of the 0.051 cm (0.020 inch) Elvax sheet and any bubbles were punctured with a razor knife. The Elvax was then positioned on the galvanized panel.

2. Cell Preparation

The cells were inverted, wiped with methanol, and painted with the Pliobond 8004 diluted adhesive. The adhesive was air-dried for 15 minutes and baked for 15 minutes at 50°C.

3. Module Assembly

The galvanized panel carrying the first layer of pottant, and cells, was cooled in a freezer. The cells were placed adhesive side down on the panel. The assembly was thawed, painted with adhesive on the top side, air-dried, and baked. The edging was applied and the assembly was placed in the freezer along with the 0.070 inch (0.178 cm) thick Elvax top pressing. After cooling, the Mylar was peeled from the Elvax and the upper Elvax layer was positioned on the laminate. The following assembly was laid up to press the pottant into position with uniform loading:

2	30.5 x 30.5 x 0.32 cm aluminum panels	}	Above Pottant
1	31 x 31 x 0.32 cm corrugated board		
2	31 x 31 x 0.32 cm foam silicone rubber		
1	31 x 31 x 0.08 cm silicone rubber sheet		
1	Module (galvanized steel, Elvax, cells, Elvax)		
1	31 x 31 x 0.32 cm silicone rubber sheet	}	Underside Support
1	31 x 31 x 0.32 cm aluminum panel		
1	31 x 31 x 0.32 cm corrugated board		

The assembly was taped to prevent slippage and was cooled for 1 hour in a freezer. The assembly was then placed in a 100°C vacuum oven with a 7.8 kilo weight on top for 1.5 hours.

The assembly was cooled and removed from the stack. The projecting wires were bent to a vertical spiral configuration to prevent leverage on the embedded interconnects during cure. The laminate was placed on a

steel block in a 150°C oven for 15 minutes, removed, bubbles punctured, Elvax stock added where needed, and the laminate baked for 45 minutes further at 150°C. The laminate was cooled and the aluminum edging removed.

4. Cover Film Application

The laminate was cooled in a freezer. Union Carbide 7158 volatile silicone fluid was applied to the surface in a thin layer (1 gram per square foot) and the top cover film was dropped onto the surface while under slight tension. The film was folded under the edges of the galvanized steel and the laminate was heated at 100°C for 15 minutes. The volatile silicone was found to have evaporated and the cover film was glued securely in place.

C. Cost of Materials

The following tabulation presents construction costs, both present and projected, for the EVA/Galvanized Steel module system:

<u>Material</u>	<u>Thickness (Mils)</u>	<u>Grams Used Per Ft²</u>	<u>Construction Costs (\$/Ft²)</u>	
			<u>Present</u>	<u>Projected, 1986</u>
. Cover Film				
UV-stabilized Acryloid B48N	2	5.2	0.019	0.019
. Adhesive				
Pliobond 8004	-	4.6	0.021	0.021
. Pottant				
Elvax 150 (Formulation A7827-1)	90 (a) (25)	203 (56)	0.262	0.072
. Adhesion Promoter				
Z-6032	-	~ 0.001	Insignificant	Insignificant
<hr/>				
Total, excluding substrate		-	0.302	0.112
<hr/>				
Substrate - Galvanized Steel	68	-	0.56	0.56
<hr/>				
TOTAL			0.96	0.67

(a) Numbers in parentheses are 1986 projections.

Module III. - Ionomer/Rigid PVC

A. Materials of Construction

The following tabulation lists the various materials utilized in the construction of the Ionomer/Rigid PVC module.

<u>Material</u>	<u>Manufacturer</u>	<u>Nature</u>	<u>Bulk Cost, \$/Lb</u>
. Substrate			
Geon 85707	Goodrich	Rigid PVC	0.30
. Cover Film			
Acryloid B48N	Rohm & Haas	Acrylic	1.18
. Pottant Materials			
Surlyn 5030	DuPont	Ionomer resin	1.05
Elvax 150	DuPont	Ethylene/vinyl acetate	0.55
. UV Absorbers			
Tinuvin P	Ciba-Geigy	Substituted benzotriazole	9.25
Tinuvin 328	Ciba-Geigy	Substituted benzotriazole	7.60
Tinuvin 770	Ciba-Geigy	Hindered amine	13.20
. Adhesive			
Pliobond 8004	Goodyear	Acrylic, pressure-sensitive	0.73

B. Module Assembly

. Material Preparation

1. Substrate

Compression-molded sheets of B. F. Goodrich Geon 85707, a rigid PVC compound, were utilized as substrate material.

A plaque was sanded on one side, the sanded side cleaned with toluene, and the plaque then annealed for 24 hours at 55°C to remove any molded-in stresses.

2. Pottant

The pottant, DuPont Surlyn 5030 ionomer, Lot 813007, a powder grade sodium ionomer containing a UV absorber and an antioxidant, was dried at room temperature under vacuum.

3. Cover

UV-stabilized Acryloid B48N, Ronm & Haas, was utilized as a cover film.

. Fabrication Procedure

1. Substrate Preparation

Holes (3/16 inch, 0.48 cm) were drilled in the vinyl sheet to accommodate the electrical connector pins. The terminal pins were cleaned with toluene, the heads tinned with rosin core solder, and then pressed into the vinyl substrate using a small quantity of epoxy adhesive (50 Epon 828, 50 Versamid 125).

The diluted acrylic adhesive previously described for the EVA/galvanized system (50 Pliobond 8004, 50 ethyl acetate) was applied in two coats to the vinyl over the areas marked for cell placement. Each coat was brushed on and air-dried for 15 minutes plus additional drying for 30 minutes at 55°C.

2. Cell Preparation

The three cell stringers were cleaned with methanol and toluene. The cell and interconnect back sides were painted with a 50 percent Pliobond 8004/50 percent ethyl acetate solution. Two coats were applied, each dried for 15 minutes at room temperature plus 30 minutes at 55°C.

A 0.020 inch (0.05 cm) thick compression-molded sheet of crosslinked Elvax between Mylar sheets was marked with nine circular cell outlines (9.1 cm diameter), which were then cut from the sheet in "cookie cutter" fashion to provide stress relief pads under the cells.

3. Cell-to-Module Assembly

The previously prepared substrate, cell stringers, and Elvax pads - along with the materials described in the following lay-up assembly - were placed in a freezer at -20°C. After a 30-minute cooling period, the Mylar backing was removed from the Elvax pads and the cells were positioned on the substrate with the Elvax pads (to provide stress relief) underneath. The interconnects were soldered to the terminal pins and the following materials were laid up in the freezer:

2	30.5 x 30.5 x 0.32 cm aluminum panels	}	Over the Module
1	31 x 31 x 0.32 cm corrugated board		
2	31 x 31 x 0.32 cm foam silicone rubber		
1	31 x 31 x 0.08 cm silicone rubber sheet		
1	Assembly (vinyl substrate, Elvax pads, cells)		
1	31 x 31 x 0.32 cm silicone rubber sheet	}	Under the Module
1	31 x 31 x 0.32 cm aluminum panel		
1	31 x 31 x 0.32 cm corrugated board		

The assembly was then placed in a 100°C vacuum oven with a 7.8 kg weight on top and vacuum applied for 1 hour. After being cooled the entire surface was painted with two coats of 50 percent Pliobond 8004/50 percent ethyl acetate - each coat dried for 15 minutes at room temperature plus 30 minutes in a 55°C air oven.

4. Encapsulation

A strip of masking tape was run around the perimeter of the module to serve as a constraining wall. The dry Surlyn 5030 powder was weighed onto the module surface and smoothed to uniform thickness using a Teflon-coated spatula.

The module was placed on a galvanized steel support plate and then put on a preheated steel block in a 150°C vacuum oven for 20 minutes. The assembly was then transferred to a 150°C air oven for an additional 15 minutes to complete the fusion.

5. Cover Film Application

The acrylic cover film and acrylic pressure-sensitive acrylic adhesive coating were applied as described in the Elvax/galvanized steel module system (No. II).

The acrylic cover film was sealed to the edges of the vinyl substrate to protect the edges of the lamination interfaces from moisture.

C. Cost of Materials

The following tabulation presents construction costs, both present and projected, for the Ionomer/Rigid PVC module system:

<u>Material</u>	<u>Thickness (Mils)</u>	<u>Grams Used Per Ft²</u>	<u>Construction Costs (\$/Ft²)</u>	
			<u>Present</u>	<u>Projected, 1986</u>
. Cover Film				
UV-stabilized Acryloid B48N	2	5.2	0.019	0.019
. Adhesive				
Pliobond 8004	-	6.8	0.030	0.030
. Stress Relief Pad				
Elvax 150	20 (a) (5)	28.7 (7.2)	0.037	0.009
. Pottant				
Surlyn 5030	50 (80)	80 (75)	0.185	0.174
Total, excluding substrate			-	0.271
Substrate - Geon 85707 PVC			0.63	0.63
TOTAL			0.90	0.85

(a) Numbers in parentheses are 1986 projections.

Module IV. - Acrylic/Phenolic

A. Materials of Construction

The following tabulation lists the various materials utilized in the construction of the Acrylic/Phenolic module.

<u>Material</u>	<u>Manufacturer</u>	<u>Nature</u>	<u>Bulk Cost, \$/Lb</u>
. Substrates			
FM 4007	Fiberite	Phenolic	0.85
Dylark 238	Arco Polymer	Styrene-maleic copolymer	0.35
. Cover Film			
Acryloid B48N	Rohm & Haas	Acrylic	1.18
. Pottant Material.			
QR 667	Rohm & Haas	Acrylic hot melt	1.40
. UV Absorbers			
Tinuvin P	Ciba-Geigy	Substituted benzotri- azole	9.25
Tinuvin 328	Ciba-Geigy	Substituted benzotri- azole	7.60
Tinuvin 770	Ciba-Geigy	Hindered amine	13.20

B. Module Assembly

. Material Preparation

1. Substrate

Plaques of a 30-mil compression-molded short glass filled phenolic resin, Fiberite FM 4007, were utilized as a substrate.

2. Pottant

As a pottant, Rohm & Haas QR-667 acrylic hot melt was used, as received.

3. Cover Film

For a cover film, the same UV-stabilized Acryloid B48N (Rohm & Haas) used in all previous systems was utilized here. For this application, the Pliobond 8004 adhesive was not cast on the acrylic film. The QR-667, because it is a hot-melt adhesive with high surface tack, serves to hold the film in place.

. Fabrication

1. Substrate Preparation and Cell Assembly

As with all system, three stringers consisting of three cells were laid out on the phenolic substrate, marked to ensure proper location. The positions of the terminal pins were marked and holes were drilled (3/16 inch, 0.48 cm).

Terminal pins were cleaned with toluene and tinned with rosin core solder. The pin shafts were coated with epoxy (50 Epon 828/50 Versamid 125) and pressed into the holes using an arbor press.

The cell stringers were cleaned with methanol/toluene, and again with methanol, and soldered into place on the substrate.

2. Encapsulation

The edges of the phenolic substrate were fitted with L-shaped aluminum walls lined with glass-reinforced Teflon film for release from the hot-melt pottant after fusion. The walls were held in place with masking tape and the substrate then preheated for 30 minutes in a 150°C air oven.

QR-667 was cut into 15-20 gram pieces and arranged in a uniform distribution on the preheated substrate. The module was transferred to a 150°C vacuum oven for 2 hours to permit deaeration and flow of the QR-667.

3. Cover Film Application

The application of the acrylic film is similar to the previously described systems.

The walls were removed from the module and the surface of the QR-667 was coated with 1.1 to 1.5 grams of Volatile Silicone 7158. The film was then laminated to the surface of the QR-667 using light pressure to express any trapped air and silicone. The film was trimmed, with the excess being folded under and bonded to the substrate.

The assembly was transferred to a 100°C oven for 15 minutes, then removed. Any trapped air or silicone was removed by puncturing the warm film with a needle and expressing air and fluid with slight pressure. The adhesive quality of the pottant then held the cover in place.

C. Cost of Materials

The following tabulation presents construction costs, both present and projected, for the Acrylic/Phenolic module system:

<u>Material</u>	<u>Thickness (Mils)</u>	<u>Grams Used Per Ft²</u>	<u>Construction Costs (\$/Ft²)</u>	
			<u>Present</u>	<u>Projected, 1986</u>
. Cover Film				
UV-stabilized Acryloid B48N	2	5.2	0.019	0.019
. Pottant				
QR-667 - Present	90	250	0.771	-
- Projected	(a)	24	-	0.074
. Stress Relief Pads				
Elvax 150	5	7.2	-	0.009
. Filler (Around Cells)				
UV-stabilized Polystyrene	28	25	-	0.015
Total, excluding substrate			0.790	0.117
Substrate -				
FM-4007 Phenolic	250	1150	2.15	-
Dylark 238, sty- rene/maleic anhy- dride	273	700	-	0.53
TOTAL - FM-4007 Phenolic			2.94	-
Dylark 238			1.32	0.64

(a) 3 mils over filler; 10 mils over cells.

Using the present design, the system cost is \$1.32 per square foot (styrene/maleic copolymer substrate). The following design modifications are proposed to overcome the limitations imposed by the high cost (\$1.40/pound) of the QR-667 acrylic hot melt:

1. Use of less expensive Elvax 150 (5-mil pads) under the cells in place of QR-667.
2. Use of an injection-molded, inexpensive polymeric filler around the cells.

The material of choice for filler is polystyrene. A grade incorporating UV absorbers could be obtained for 28 cents per pound. The design would utilize the filler at a thickness of 28 mils around the cells. QR-667 would then be flowed over the assembly to a thickness of 10 mils over the cells and 3 mils over the filler.

This 1986 projected design could be constructed for 11.7 cents per square foot, not including substrate material. This leaves a substrate price of 13.3 cents per square foot, a reasonable cost for a wood-based material, to bring the entire system within the LSSA goal figure.

Fabrication of Single Modules

Single modules of each of the following descriptions were fabricated and submitted to JPL for demonstrations purposes only.

. A8145-1 - EPDM on Vinyl Liner on Honeycomb Support

Norfield Company kindly provided samples of a heat-expanded styrene honeycomb type structure. A clear EPDM (ethylene propylene diene rubber, Nordel 1320) formulation developed previously was modified with a lower temperature peroxide for 150°C cure. The assembly consisted of:

- . EPDM (50-mil)
- . Cells primed with Union Carbide A-174 silane
- . EPDM (20-mil)
- . Vinyl (B. F. Goodrich Compound 86781) (20-mil), coated with Goodyear Pliobond 8004

Epoxy

- Norfield honeycomb (pigmented polystyrene)

The cell assembly was cured at 150°C before bonding to the honeycomb. A B-48 acrylic film containing the UV absorber was utilized for outdoor aging.

Known problems with this assembly include:

1. The adhesives and primers utilized are marginal for EPDM.
2. The vinyl yellows in contact with the peroxide-containing EPDM.
3. The vinyl warps somewhat during the bake cycle.

- A8146-2 - Flexible Polyester on Plywood

A flexible polyester, U. S. Steel Laminac 4134, was flexibilized further with butyl acrylate monomer to serve as the pottant (withstood the impact of a 3-foot drop of a 16-gram steel ball at -20°C). The assembly consisted of:

- UV-stabilized Acryloid B48N cover film coated with Pliobond 8004
- Flexible polyester
- Cells primed with Union Carbide A-174
- Flexible polyester
- Plywood primed with Hughson Chemlok 607

The assembly was cured at 100°C and the cover film applied and shrunk on at 100°C. Known problems with this assembly include:

1. The polyester cracks in thick sections. The present polyester should only be used thin, or in conjunction with filler board (described in the next section). Modification of the polyester may also be possible.
2. Adhesion to the cells is marginal.

. A8147-3 - Crosslinkable Acrylic on Hardboard

Rohm & Haas QR-667 soft acrylic was mill-compounded with di- and trifunctional monomers, peroxide, antioxidant, and UV screening agent. It was found that glycol dimethacrylate - e.g., Rohm & Haas X-970 - gave a fast, tight cure; but the pot life at 150°C was insufficient to permit deaeration. Triallyl isocyanurate gave adequate pot life for deaeration and cured in 2 hours. A t-butyl perbenzoate (peroxide) level of 0.4 percent did not effect good cure, but 0.8 percent was adequate.

The filler board concept was introduced at this point. The filler board displaces much of the acrylic and lowers the cost. A Mead Pan-L-Board was cut for nine cells with a flycutter. The terminal pins in the hardboard were countersunk to avoid interference with the filler. The cells were aligned, bonded to the substrate, and the filler board bonded into place. Otherwise the assembly procedures were similar to those previously described.

The assembly consisted of:

- . UV-stabilized Acryloid B48N cover film
- . Crosslinkable acrylic/filler board (dried)
- . Cells (cleaned)
- . Epoxy (35/65, Epon 828/Versamid 125)
- . Sanded hardboard (Masonite Corporation) (dried)

The acrylic was flowed out and deaerated at 150°C under vacuum, then cured under nitrogen for 2 hours (150°C). The cover film was applied and shrunk on at 100°C. No immediate problems were encountered.

. A8148-4 - Aliphatic Urethane on Filled Styrene Copolymer Board

The assembly consisted of:

- . Quinn Q-621/Q626 two-part aliphatic urethane
- . Filler board - Dylark 232
- . Cells (cleaned)
- . Epoxy/Versamid 125, 35/65

- . Dylark 232 (styrene-maleic) milled with calcium carbonate (70/30), molded into 12" x 12" x 0.25" substrate

The Quinn material was mixed at room temperature, deaerated, poured onto the cells, deaerated, and cured at 100°C. A B48N cover film is recommended for outdoor use.

Problems encountered are:

1. The Quinn material is slow to deaerate, but additive should overcome this problem.
2. The Dylark was tried for a 150°C cure pottant, but warped. Use of Dylark is confined to approximately 100°C process.

WEATHERING STUDIES

Twenty-four materials were originally selected for study in this program, on the basis of transparency and weatherability. Although most of the originally investigated polymers were found to be cost-ineffective and/or not amenable to any processing method that could be used to encapsulate solar cells. A study of their properties provided valuable experience towards the selection of more successful candidates. The choice of materials was directed solely at transparent pottants and did not include other possible construction elements such as substrates, however some of the polymers could possibly serve as protective outer covers in later phases of this program.

As a continuation of this original program, data is now being obtained from outdoor exposures as well as from the initial accelerated aging exposures so that correlations between natural and artificial accelerated environments may be made. From these original twenty-four plastics a group of eleven were chosen for outdoor weathering studies. Tensile bar samples were put outdoors in Florida and Arizona at 45° angle exposure, and in Arizona in the EMMAQUA (a device combining natural sunlight with artificial acceleration by means of mirror concentrators plus a water spray). Specimens were withdrawn at various time intervals and elevated for optical transmission and mechanical properties. Two materials required special preparation: PVB and Q3-6527 gel. In the case of polyvinyl butyral (PVB - "Saflex" PT-10, it was desired to expose the material behind glass in order to simulate use conditions. Bonding to the glass occurred, however, and necessitated that the material be sandwiched between 1 mil films of FEP first to serve as release surfaces. The edges of the tensile bar/FEP/glass sandwich were sealed with silicone rubber to avoid contamination. Q3-6527 dielectric silicone gel was exposed by pouring the uncured liquid into a glass cell (3-1/2" x 2" x 0.062") and permitting polymerization to take place. The cell openings were also sealed with DC-732 silicone rubber to avoid water and dust contamination. Only a visual

inspection could be used to evaluate this compound since it is not sufficiently manageable to put in a spectrometer or Instron machine.

Tables 4-14 through 4-16 tabulate the results of optical transmission and mechanical properties of the polymers after exposure to three conditions; 6 months - Florida - fixed angle, 4 months EMMAQUA and 8 months EMMAQUA. These properties are further compared to weather-o-meter and RS-4 sunlamp exposures in Tables 4-17 through 4-19.

The most consistent loss of properties was noticed for PVB. Every test specimen in every condition flowed to an unrecognizable mass that could not be tested. The light yellow color of the melted polymer suggests that degradation has also occurred. Experiments conducted by the manufacturer (Monsanto) are in agreement with our results, and they indicate that an oxygen/UV synergism occurs that degrades this compound rapidly. The exclusion of air is the reason why PVB becomes stable and functions successfully as a safety glass interlayer. Monsanto insists that this product (Saflex PT-10) is not intended for outdoor use in nonlaminated constructions.

Consistent results were also obtained with the Q3-6527 dielectric gel. All specimens retained high optical clarity (visual inspection) and showed no signs of discoloration. Bubbles, however, formed in all specimens, usually along the edges of the cell but occasionally forming long trails through the center. This effect may possibly be the result of shrinkage due to continued polymerization during the exposure period. Unexposed control specimens developed the same difficulty.

A comparison of optical transmission values (Table 4-19) reveals the most stable materials retaining over 80% of the original property are Halar, Plexiglas DR, FEP, KEL-F and Plexiglas V-811. As may be expected, these are fluorocarbons and acrylics. Sylgard 184 silicone rubber would have performed well except for dust retention on the

surface which reduced the transmission by about 50 percent. Tedlar film produced poor results, losing 60 percent or more of its transmission in all conditions. Cellulose acetate-butvrate (Tenite 479) either melted or broke in all exposures except EMMAQUA, 4-month. The transmission retained was still only 48 percent of original. Tensile test specimens surviving the 4-month EMMAQUA exposure retained less than one percent of the original elongation and 18 percent of the original tensile strength.

Most of the other polymers maintained their tensile strengths well during outdoor aging. The only conspicuous losses occurring for Sylgard 184 and Plexiglas V811, which decreased an average of 40 percent under the Florida and EMMAQUA conditions. RS-4 fluorescent sun-lamp exposure is a much more severe condition in comparison. Plexiglas DR, almost unaffected by the outdoor exposures, lost 72 percent tensile strength after 240 days' exposure.

Ultimate elongation values (Table 4-17) did not decrease particularly badly except for Lexan which dropped by more than 80 percent. Elongations after RS-4 exposure were noticeably more affected, Plexiglas DR losing 94 percent of original and Plexiglas V811 decreasing by 70 percent.

Variations in mechanical properties versus temperature were also part of the original endeavor to characterize material performance. Tables 4-20 through 4-23 present the measurements of tensile strength, elongation at break, tensile modulus, and yield strength for twelve polymers at six temperatures between -20°C and +80°C. Generally, tensile strength and yield strength can be seen to decrease with increasing temperature, while modulus and ultimate elongation show considerable variation, depending on the material and temperature. The increase in modulus of the two silicone rubbers at higher temperatures is possibly due to the activation of residual polymerization mechanisms.

General conclusions drawn from inspection of the data obtained to date indicate that the three outdoor conditions are less severe than weather-o-meter and much less severe than fluorescent sunlamp. Both acrylic compounds, particularly Plexiglas DR weather well, maintaining physical and optical properties. Lexan loses mechanical strength but retains optical properties. Tedlar undergoes severe optical transmission loss, but retains physical strength. The fluorocarbons, as usual, are the most weatherable.

It is too soon to draw any definite conclusions, but it is hoped that the EMMAQUA experiments and information resulting from the other accelerated test methods can eventually be assembled into a coherent presentation from which positive correlations may be drawn. Conclusions resulting from this study may be valuable in the future for the rapid selection and evaluation of candidate encapsulation materials.

5. CONCLUSIONS

1. The flat-plate module construction is assumed to be the most efficient collector surface.

Based on the assumption, nine design variations were considered from which three basic types could be visualized: Substrate bonded, superstrate bonded and laminated. All designs use one or more of six construction elements in their fabrication. These construction elements are: substrate, superstrate, pottant, adhesive, outer cover, back cover.

2. The results of materials surveys were useful in generating first-cut estimated cost allocations for each construction element, which are:

<u>Construction Elements</u>	<u>Cost Allocation (\$/Ft²)</u>
Substrate/Superstrate	0.14
Pottant	0.06
Adhesive	0.04
Outer cover	0.01
Back cover	0.05

3. Six commercially available transparent polymers suitable for use as pottants have been identified (Table 3-5) with encapsulation costs from \$0.017 to \$0.089 per square foot. With the exception of the acrylics, these materials all have the common deficiency of being sensitive to and degraded by ultraviolet light. Successful use will therefore depend on adequate UV screening.

Four compounds are of major interest at this time: ethylene-vinyl acetate copolymer (EVA), ethylene-propylene rubber (EPR), polyvinyl chloride plastisol (PVC), and acrylic hot-melt compounds.

4. Coefficients of linear thermal expansion were measured for thirteen polymers and found to be eight to sixty times that of silicon. Thermal cycling will obviously cause stresses to form at any polymer/cell interface. The encapsulant material must therefore be of sufficiently low modulus to accommodate expansion differentials.
5. Of the transparent superstrate materials examined to date, glass is still the most cost-effective option at a calculated cost of \$0.29/ft.²
6. In terms of the 1986 encapsulation target of \$0.25/ft.² encapsulation cost, acrylic polymers will not be recommended for structural load bearing functions. Based on wind deflection loads, the thickness required for either is 0.315 inch - which, at a resin cost of \$1.42 per pound, calculates to \$1.77 per square foot. This figure exceeds the current cost allocation by a factor of seven.
7. In the survey of substrate materials examined to date (wood, glass, plastics, metals), composites of wood and paper products stand out as the most promising and cost-effective candidates. The high strength-to-weight ratio, known technology, and renewability of raw materials make wood products attractive. A cost in the order of \$0.12/ft.² (particle board) makes this class of materials the least expensive yet found.
8. Upgrading the ultraviolet stability of various polymers in this program by internal compounding has been successful primarily in terms of improving optical characteristics. Mechanical properties, however, show little, if any, improvement in performance.
9. The ability to formulate ultraviolet screening coatings of low cost has been demonstrated. Using solution acrylic polymers (Rohm & Haas, Acryloid series) as vehicles, coatings of one mil thickness were found to have low, and in several cases zero, percent transmittance in the range of 290-350 nm. The cost of these coatings was in the order of \$0.01 per square foot per mil.

10. The efficiency of the UV-Acryloid coatings has been demonstrated. Coated specimens of polypropylene survived approximately fifteen times the exposure dose of RS-4 radiation over uncoated control specimens. The primary failure mode appears to be delamination of the coating from the polypropylene.
11. The plasma spray process has not been successful on the trial module encapsulations attempted so far. Cell fracturing and solder melting have been the predominant modes of failure. The process is in its infancy, however, and does demonstrate the potential to be of use in future phases of the LSSA project.

6. RECOMMENDATIONS

1. Methods for upgrading the UV and weathering resistance of low-cost transparent polymers, while retaining clarity, need emphasis.

Through the use of appropriate coatings and stabilizers, UV sensitive polymers previously considered unusable may become viable potplants.

Protective coatings must have three basic properties: ultraviolet screening, soiling resistance, and mechanical flexibility.

It is recommended that acrylic formulations, including solvent based and latex types, be investigated further as vehicles for UV absorbing agents.

2. The most inherently weatherable materials identified to date are fluorocarbons, silicones, glass, and acrylics. Acrylics are the only weatherable polymers showing potential as potplants due to their low cost and projected processability. Currently, no commercially available acrylic elastomer exists that is suitable for use due to the excessively high modulus. Some hot-melt adhesive acrylics are soft enough to provide stress relief, but the absence of crosslinking causes high creep and lack of resiliency. The development of a clear, processable and crosslinkable acrylic elastomer is recommended.
3. It is recommended that a critical analysis of adhesive characteristics of specific encapsulation systems be performed. This study would include optical transmission and variation in bond strength of lap-shear specimens with respect to ultraviolet exposure, Weather-Ometer exposure, water immersion, etc. Additionally, field testing of adhesively bonded experimental modules should be used to evaluate final selections.
4. Due to the proportionally high cost of substrate materials, emphasis needs to be placed on investigation of honeycombs, cellular structures, and other design concepts aimed at very high strength-to-weight and cost-effective structures.

5. Because wood and paper products hold promise as substrates, it is recommended that a study of their performance under actual weathering conditions be conducted, including a survey of preservation techniques required to optimize the service life.

7. FUTURE ACTIVITIES

1. Reporting and correlation of mechanical and optical properties of polymer specimens initially selected at the onset of this program and exposed to a variety of aging conditions. Exposure modes to be included are:
 - a. Weather-Ometer
 - b. RS-4 Fluorescent Sunlamp
 - c. Fixed-Angle (45°S) exposure in Florida and Arizona
 - d. EMMAQUA exposure at Desert Sunshine Exposure Tests, Inc.

An evaluation of acceleration factors will hopefully result from this study. Thirteen polymers are being examined and are near completion of their designated exposure times.

2. Surveys will be continued to find materials appropriate for use for each one of the six identified construction elements.
3. A study of the cost effectiveness of structurally designed materials such as honeycombs and extruded cell structures demonstrating high strength-to-weight ratios will be conducted.
4. Investigations will be continued into inexpensive, load-bearing wood product substrates to discover the most cost-effective compositions. Useful contacts will come from companies such as Hexcell Corporation, Masonite Corporation, St. Regis Paper Company, and Forest Products Laboratory.
5. A new class of substrates will be investigated based on resin-bonded inorganics and waste materials such as fly ash, ground corn cobs, slate dust, etc.

6. Outer cover formulations will receive emphasis in the oncoming year. These materials will serve to protect the underlying substrates and pottants and must demonstrate the following properties:
 - a. Broad temperature flexibility, from -40°C to $+90^{\circ}\text{C}$ (JPL specification).
 - b. Resistance to soiling by wind-blown dust and dirt over the temperature range mentioned.
 - c. Highest possible transparency.
 - d. High UV absorption from nonextractable additives.
 - e. Closely matched coefficient of thermal expansion to underlying composition.
 - f. Amenability to automated coating process.
7. Further investigations will be conducted to maximize the cost/performance of the four basic low-cost potting materials: ethylene/vinyl acetate, polyvinyl chloride (plastisol), ethylene/propylene rubber, and acrylic copolymer.
8. Because of the inherently high weatherability of acrylics, an experimental research and development program will be aimed at the creation of a transparent, pourable, room-temperature cure acrylic pottant. This material may be formulated to have processing characteristics similar to Sylgard 184 silicone rubber.

Commercial materials will be examined first, then modified commercial compounds, then synthesized compositions.
9. Solar cells fracture from thermal excursions when encapsulated in very hard materials due to the lack of stress relief. Experiments will be conducted to determine the limiting modulus of the potting material to prevent cracking.

10. Various automatab'e processing methods will be investigated and used for actual construction of miniature solar modules.
11. Miniature modules will be built according to JPL design specifications using materials, processes, and techniques identified from previous surveys and experiments. The modules will use realistic construction methods and accurately represent the 1986 cost goals of \$0.25/ft². I/V power curves will be provided by Solar Power Corporation before and after encapsulation.

APPENDIX

TABLES

TABLE 3-1

Transparent Plastics Survey
Materials Under 50 Cents/Pound

Generic Type	Trade Name	Manufacturer	Processability		(a,b) Survival Prognosis: Max. Span of Years to Failure	(a,c) Upgrading Potential in Years			Tensile Modulus (10 ⁹ psi)	Refractive Index	Density (g/cc)	Thermal Expansion (10 ⁻⁵ /°C)	Cost (\$/lb)	Cost/Vol. (¢/in. ³)	FLL Cost (\$/sq. ft.)	Cover Cost (\$/sq. ft.) 0.0005 lb.	Encapsula- tion Cost (\$/sq. ft.)
			Liquid	Solid (°F)		10	20										
Hydrocarbon polymers	Polyvol G100	Valsicol		<250	<1	P	P	G		1.50	1.0		0.30	.0108	.0072	.0078	.0150
Hydrocarbon polymers	X 125, 685	Neville	Yes		<1	P	P	G			1.0		0.23	.0083	.0055	.0059	.0110
Polyvinyl chloride	Geon 103	Goodrich		>250	1-5	G	P	G	2-4	1.50- 1.55	1.32- 1.40	5-10	0.26	.0131	.0087	.0094	.0181
Polystyrene	Cosden 500	Cosden Oil		>250	1-5	P-G	P-P	G	4-5	1.59	1.04- 1.09	6-8	0.27	.0106	.0071	.0076	.0147
Polypropylene	Profax 6523	Hercules		>250	<1	P-G	P-P	G	1.5- 2.5	1.49	0.90- 0.93	2-20	0.30	.0101	.0067	.0073	.0140
Poly-4-methyl styrene	Resin 18	A'KO		>250	1-5	P	P	G	4-5	1.60	1.08		0.28	.0109	.0073	.0078	.0151
High-density polyethylene	Dow 75731	Dow		>250	1-5	G	P	G	0.75- 1.60	1.26*	0.92- 0.96	10-20	0.29	.0100	.0067	.0072	.0139
Low-density polyethylene	DYNH	UCC		250	1-5	G	P	G	0.14- 0.38	1.16	0.90- 0.98	10-20	0.31	.0109	.0073	.0078	.0151
Ethylene/vinyl acetate	EVA 3185	Du Pont		<250	1-5	G	P	P-G	0.002- 0.04	1.51- 1.54	0.92- 1.10	10-20	0.50	.0190	.0132	.0142	.0274
Plasticized PVC copolymer	Numerous			>250	1-5	G	P	P-G	0.01- 0.20		1.2		0.30- 0.40	.0173	.0116	.0124	.0240
Ethylene/ethyl acrylate				<250	1-5	G	P	P-G	0.03- 0.4	1.51	0.90- 0.93	16-25	0.48	.0161	.0108	.0116	.0224
Isophthalic polyester	Acropul	Ashland	Yes		1-5	G	P	P-P	(g) 4-6		1.2		0.37	.0160	.0107	.0115	.0222
Styrene/acrylonitrile	Lustran	Monsanto		>250	1-5	P	P	G	5.0	1.57	1.06	7	0.40	.0153	.0102	.0110	.0212

(d) A flexible polyester is available

Code: G = Good; P = Fair; P = Poor

* Marlex 50 at 130°C

** Alathon 10 at 90°C

(a) Springborn Laboratories educated opinion

(b) No UV absorber

(c) Protected with an internal UV absorber and an external coating or sheet containing a UV absorber.

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TABLE 3-1 (Continued - 2)

Materials Under 50 Cents/Pound

Generic Type	Trade Name	Manufacturer	Processability		Survival Prognosis: Max. Span of Years to Failure	Upgrading Potential in Years		Hydrolysis Resistance	Tensile Modulus (10 ⁵ psi)	Refractive Index	Density (g/cm ³)	Thermal Ex- position (10 ⁻⁵ hr/in./°C)	Cost (¢/lb)	Cost/Vol. (¢/in. ³)	Fill Cost (¢/ft ³)	Cover Cost (¢/ft ²)	Encapsula- tion Cost (¢/ft ²)
			Liquid	Solid (or)		10	20										
Styrene/butadiene	Kraton	Shell		>250	<1	F	P	G	0.3- 0.5	1.52- 1.55	1.04- 1.06	3-10	0.35- 0.43	.0164	.0110	.0118	.0228
Propylene/ethylene	Polyallomer 502LE	Eastman		>250	<1	F	P	G		1.49	0.90	8-10	0.395 (e)	.0128	.0086	.0092	.0178
Neopentyl glycol polyester.	Cargill 5446	Cargill	Yes		1-5	G	P	F	(f) 4-7		1.2		0.38	.0164	.0110	.0118	.0228
Ethyl propylene rubber	Nordel	Du Pont		250	1-5	G	P	G	0.01- 0.50	1.52- 1.55	0.7- 1.20		0.49	.0212	.0142	.0152	.0294
Chlorinated polyethylene	CPE	Dow		250	1-5	P-G	P-P	G	~0.02	1.52	1.16- 1.25		0.44	.0198	.0133	.0142	.0275
Polybutylene	Wintron	Witco		>250	<1	P	P	G	0.26- 0.50	1.50	0.91- 0.92	15	0.48	.0159	.0106	.0114	.0220
PVC Plastisol copolymer		Numerous	Yes		1-	G	P	G	0.02- 0.20		1.2		0.50- 0.60	.0260	.0174	.0187	.0361

(e) Cost, with UV absorber, 0.465 \$/lb

(f) A flexible polyester is available

TABLE 3-2

Transparent Plastics Survey

Material's Coating 50 Cents to \$1.00/Pound

Generic Type	Trade Name	Manufacturer	Processability		(a,b) Survival Prognosis: Max. Span of Years to Failure	(a,c) Upgrading Potential in Years		(a) Resistance	Tensile Modulus (10 ⁵ psi)	Refractive Index	Density (g/cm ³)	Thermal Ex- pansion (10 ⁻⁵ in/in/°C)	Cost (\$/lb)	Cost/Vol. (\$/in ³)	Fill Cost (\$/ft ²)	Cover Cost 0.0005 lb. (\$/ft ²)	Encapsula- tion Cost (\$/ft ²)
			Liquid	Solid (°F)		10	20										
Unfilled cast phenolic	Gen-L	G.E.	Yes		<1	P	P	G	4.0- 7.0	1.5- 1.7	1.24- 1.30	6.8	0.50- 0.60	.0282	.0188	.0203	.0391
Modified polyethylene terephthalate	Kodac PETG	Eastman		>250	1-5	G	F	P-G	2.9		1.27		0.55	.0252	.0169	.0181	.035
Clear acrylonitrile/buta- diene/styrene (MBS)	Cyclocac CIT	Marbon		>250	1-5	P-G	P-P	G	2.9- 3.4	1.54	1.07	9.5	0.48- 0.58	.0224	.0150	.0161	.0311
Ethylene/acrylic acid	EAA 435	Dow		<250	1-5	P-G	P-P	G	~0.06	1.48	~0.43		0.50	.0077	.0051	.0055	.0106
Acrylic multipolymer	XT 250	Am. Cyanamid		>250	1-5	F	P	G	3.1- 4.3	1.52	1.11	6-9	0.53	.0212	.0142	.0153	.0295
Polybutadiene	Poly BD	ARCO	Yes		<1	P	P	G	.005- .05	~1.50	0.97		0.62	.0217	.0145	.0156	.0301
Ionomer	Surllyn 1707	Du Pont		<250	<1	P-G	P-P	F	0.2- 0.5		0.94- 0.96		0.62- 0.66	.0228	.0153	.0164	.0303
Acrylonitrile/rubber/multi- polymer	Barex	SOHIO		>250	1-5	F	P	G	4.9	~1.50	1.15		0.65	.0269	.0180	.0194	.0374
Melamine formaldehyde*	Cymel	Am. Cyanamid	Yes		5-10	G	P-G	G	11.0	-	~1.50	4.5	0.55- 0.60	.0325	.0217	.0234	.0451
Polybutadiene telomer		Lithium Corp.	Yes		<1	P	P	P-G	5.6	1.49	0.97		0.70	.0245	.0164	.0176	.034
Polyvinyl alcohol	Gelvatol	Monsanto		<250	1-5	F	P	P	2-4	1.45	1.19- 1.27	10	0.76	.0348	.0233	.0250	.0483
Cellulose propionate	Tenite	Eastman		>250	1-5	G	P	F	0.1- 2.15	1.48	~1.25	11-16	0.85	.0383	.0257	.0276	.0533

(a) Springborn Laboratories educated opinion

(b) No UV absorber

(c) Protected with an internal UV absorber and an external coating or sheet containing a UV absorber.

Code: G = Good; P = Fair; F = Poor

*Not sold unfilled; data are on cellulose-filled product.

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TABLE 3-2 (Continued - 2)
Materials Costing 50 Cents to \$1.00/Pound

Generic Type	Trade Name	Manufacturer	Processability		Survival Prognosis: Max. Span of Years to Failure	Upgrading Potential in Years		Hydrolysis Resistance	Tensile Modulus (10 ⁵ psi)	Refractive Index	Density (g/cm ³)	Thermal Expansion (10 ⁻⁵ in/in/°C)	Cost (\$/lb)	Cost/ sq. ft. (18 in.)	Fill Cost (\$/sq. ft.)	Cover Cost (\$/sq. ft.)	Encapsula- tion Cost (\$/sq. ft.)
			Liquid	Solid (°F)		10	20										
Cellulose acetate butyrate	Tenite 479	Eastman		> 250	4-5	G	P		2.0- 2.5	1.47	1.15- 1.22	11-17	0.85	.0374	.0250	.0269	.0519
Cellulose acetate	Tenite	Eastman		> 250	1-5	G	P		3.0- 6.0	1.48	1.28- 1.32	8-16	0.87	.0415	.0278	.0298	.0576
Chlorosulfonated poly- ethylene	Hypalon	Du Pont		> 250	1-5	G	P				1.07- 1.27		0.68- 0.78	.0358	.0240	.0257	.0497
Thermoplastic polyester	Vitel	Goodyear		> 250	1-5	G	P		MA	1.50	1.31- 1.40	MA	0.90	.0455	.0305	.0327	.0632
Vinyl chloride/vinyl acetate	VYHH	UCC		> 250	1-5	P	P		MA	1.47	1.45	MA	0.50- 0.60	.0325	.0217	.0234	.0451
Linear epoxy	Phenoxyl	UCC		> 250	< 1	P-G	P				1.18		0.82- 1.17	.0498	.0333	.0358	.0691
Not Melts																	
Ethylene/vinyl acetate	Bostik 4364	Bostik (USM)	Yes		1-5	G	P-				1.0		0.80- 0.90	.0325	.0217	.0234	.0451
Polyamide	Veralon 1112 Milvex 1000	General Mills			< 1	P	P						1.73- 3.05				
Acrylic (solid materials)	329-002 68-42 Q667	Daubert Williamson Rohm & Haas		< 250	8-10 8-10	G G G	G G G						0.56(d) 3.00 1.50			.0399	.0429
Acrylics											1.1						
Copolymer	Plexiglas DR100	Rohm & Haas		> 250	5-10	G	G		2-3	1.49	1.15	4-6	0.91	.0378	.0253	.0272	.0525
Homopolymer	Plexiglas V811	Rohm & Haas		> 250	16-20	G	G		4.3	1.49	1.19	6-8	0.78	.0335	.0224	.0241	.0465
MMA/Styrene (60% MMA)	P205	Richardson		> 250	5-10	G	G		4.6	1.53	1.13	5	0.46	.0187	.0125	.0135	.0260
MMA/Styrene (85% MMA)	P301	Richardson		> 250	8-10	G	G		4.8	1.56	1.09	4-6	0.55- 0.60	.0236	.0158	.0169	.0327

MMA = Methyl Methacrylate

(d) Sounds low

TABLE 3-3

Transparent Plastics Survey
Materials Costing \$1.00 to \$4.00/Pound

Generic Type	Trade Name	Manufacturer	Processability		(a,b) Survival Prognosis: Max. Span of Years to Failure	(c,d) Upgrading Potential in Years		(e) Hydrolysis Resistance	Tensile Modulus (10 ⁵ psi)	Refractive Index	Density (g/cm ³)	Thermal Expansion (10 ⁻⁵ in/in/°C)	Cost (\$/lb)	Cost/Vol. (\$/in ³)	Fill Cost (\$/ft ²)	Cover Cost (\$/0.005 in. thick)	Encapsula- tion Cost (\$/ft ²)
			Liquid	Solid (°F)		10	20										
Epoxy urethane	Isochem UR5	Isochem	Yes		< 1	P	P	P-P	0.3- 3.5	1.60	1.2- 1.3	10-20	1.25	.0587	.0393	.0423	.0816
Castable urethane	System 30	Castor	Yes		< 1	P	P	P-P	0.1- 3.5	1.55	1.07	1.7- 7.4	1.00- 1.25	.0483	.0324	.0248	.0672
Nylon copolymer	Versalon	General Mills		< 250	< 1	P	P	P-P	1.8- 2.9	1.5	1.06- 1.08	5.2	1.75	.0683	.0459	.0492	.0949
Poly(4-methyl pentene)	TPX RT18	ICI		> 250	< 1	P	P	G	1.6- 2.8	1.5	0.83- 0.84	2.5	1.75	.0531	.0356	.0382	.0738
Polyvinyl butyral	Butvar	Monsanto		> 250	1-5	G	P	P	3	1.48	1.05		1.50	.0568	.0380	.0409	.0789
Polycarbonate (stabilized)	Lexan 123-111	GE		> 250	10-20	G	G	P	3.1	1.59	1.20	3.7	1.00	.0433	.0290	.0312	.0602
Polycarbonate(hydrogenated)	C-4	UCC		> 250	4-5	G	P	P	1.7	1.46	1.2	9.7	2.00- 4.00	.1733	.1161	.1248	.2409
MMA* casting resin	TS 520	Houphson	Yes		8-10	G	G	G	4.5	1.49	1.18	4-6	1.65	.0703	.0470	.0506	.0976
	Tame 500	B.F. Goodrich	Yes		8-10	G	G	G	4.5	1.50	1.19	4-6	1.50	.0644	.0431	.0464	.0895
Nylon 6/12	Capron	Allied Chem.		> 250	1-5	P	P	P-P	1.8- 2.9	-	1.07	5.2	2.05	.1177	.0789	.0847	.1636
Polyaryl sulfone	Udel 1700	UCC		> 250	1-5	P	P	P	3.3	1.63	1.24	3.5	3.00	.1844	.0900	.0967	.1867
Polyglycol epoxy	DER 732	Dow	Yes		1-5	P	P	P	1.5- 3.0	1.55			3.00				
Epoxy casting resin	Eccogel 1265	Emerson & Cummins	Yes		1-5	P	P	P-G	0.3- 3.5	1.54	1.20		3.50	.1517	.1016	.1091	.2108
	Stycast 1264		Yes		1-5	P	P	P-G		1.54	1.10		3.50	.1390	.0931	.1000	.1931
Polysulfone	Radel P Natural	UCC		> 250	< 1	P	P	P-G	3.1	1.60	1.29	2.8	3.00- 5.00	.2329	.1560	.1677	.3237
Diethylene glycol diallyl carbonate	CR-39	PPG		250	5	G	P	P	3	1.50	1.4	4.9	4.00	.2023	.1355	.1456	.2811

(a) Springborn Laboratories educated opinion

(b) No UV absorber

(c) Protected with an internal UV absorber and an external coating or sheet containing a UV absorber.

Code: G = Good; P = Fair; P = Poor

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TABLE 3-4

Transparent Plastics Survey

Materials Costing More Than \$4.00/Pound

Generic Type	Trade Name	Manufacturer	Processability		(a,b) Survival Prognosis: Max. Span of Years to Failure	(a,c) Upgrading Potential in Years		(a) Hydrolysis Resistance	Tensile Modulus (10 ⁵ psi)	Refractive Index	Density (g/cm ³) (d)	Thermal Ex- pansion (10 ⁻⁵ in/in/°C)	Cost (\$/lb)	Cost/vol. (\$/in. ³)	Fill Cost (\$/ft ³)	Cover Cost 0.0005 in. (\$/ft ²)	Encapsula- tion Cost (\$/ft ²)
			Liquid	Solid (°F)		10	20										
Silicone gel	63-6527	Dow	Yes		8-10	G	G	P	(d)	1.44	0.97	(d)	3.75	.1313	.0878	.0945	.1823
Cycloaliphatic epoxy	ERL 4221	UCC	Yes		4-5	G	P	P	0.1- 1.0		1.18		1.40	.0596	.0399	.0429	.0828
Polyvinylidene fluoride	Kynar 460	Pennwalt		>250	>20	G	G	G	2.18	1.42	1.76	2.0	5.00	.3178	.2129	.2288	.4417
Perfluoroethylene propylene	FEF 100	Du Pont		>250	>20	G	G	G	0.70	1.34	2.15	3-4	6.00	.4659	.3121	.3354	.6475
Ethylene/chlorotrifluoro- ethylene	Halar 500	Allied Chem.		>250	>20	G	G	G	2.23	1.45	1.68		8.50	.5158	.3456	.3714	.717
Ethylene/tetrafluoro- ethylene	Tefzel 280	Du Pont		>250	16-20	G	G	G	1.80	1.40	1.70	3-4	9.00	.5526	.3702	.3978	.7680
Hexafluoropropylene vinylidene fluoride	Viton MV	Du Pont		>250	4-5	G	P	P	(e)	1.37	1.88		10.00	.679	.4549	.4888	.9437
Silicone	Sylgard 184	Dow	Yes		10-20	G	G	P	(f)	1.43	1.05	4-5	9.02	.3419	.2287	.2462	.4749
Silicone	RTV 615	GE	Yes		10-20	G	G	P	(g)	1.43	1.05	4-5	8.84	.3351	.2242	.2413	.4655
Perfluoroalkoxy	PFA 9705	Du Pont		>250	>20	G	G	G	0.53	1.35	2.15		11.00	.8536	.5719	.6146	1.186
Silicone "glass resin"	Resin 650	Owens-Illinois	Yes		16-20	G	G	G		1.45	2.1		15.00	1.137	.7618	.8186	1.580
Chlorotrifluoroethylene	Resin 81	3M		>250	>20	G	G	G	1.72	1.38	2.1	3-4	20.00	1.516	1.014	1.092	2.106
Chlorotrifluoroethylene/ vinylidene fluoride	Kel-F 800	3M		>250	1-5	G	P	G	0.23	1.44	~2.0	3.5	20.00	1.444	.9660	1.040	2.006
Polyvinyl fluoride film	Tedlar 20	Du Pont		>250	10-20	G	G	G	3.60	1.46	1.38	2.8	5.90	.2939	.1966	.2116	.4082

Code: G = Good; P = Fair; F = Poor

(a) Springborn Laboratories educated opinion

(b) NO UV absorber

(c) Protected with an internal UV absorber and an external coating or sheet containing a UV absorber.

(d) Gel - special testing required

(e) 103 psi (200%) apparent modulus

(f) 586 psi (100%) apparent modulus

(g) 389 psi (100%) apparent modulus

TABLE 3-5

**Most Promising Transparent Polymers
for 1986 Encapsulation Potentials**

Polymer	Cost (\$/Lb)	(a) Upgrading Potential in Years		Encapsulation Cost (\$/Ft ²)
		10	20	
. Casting Polymers				
Acrylic Hot Melts	1.50-1.65	G	G	0.083
Polyvinyl Chloride Copolymer Plastisol	0.50-0.60	G	F	0.036
. Solid Polymers (Low Temperature)				
Acrylics	1.30	G	G	0.053
Ethylene/Vinyl Acetate	0.50	G	F	0.027
Ethylene/Propylene Rubber	0.50	G	F	0.029
Plasticized Polyvinyl Chloride Copolymer	0.30-0.40	G	F	0.024

(a) G = Good, F = Fair, P = Poor, based on use of a UV-absorbing outer cover, and UV upgrading of the polymer from internal compounding.

(b) Fill plus 0.005-inch coverage

TABLE 3-6

**Linear Thermal Expansion
ASTM D696**

Resin	(In./in./C°) x 10 ⁻⁵
<u>Coatings/Encapsulants</u>	
Halar 500	8.6
Plexiglas DR-61	9.3
FEP 100	11.7
Tenite 479 CAB	14.5
Kel-F 6060	7.0
PFA 9705	15.7
Plexiglas V811	6.3
C-4 Polycarbonate	9.7
Lexan 111-123	3.7
Tedlar	2.8 (a)
Sylgard 184	30.0 (a)
RTV 615	27.5 (a)
Q3-6527 Gel	1.45 x 10 ⁻³ (b)
<u>Solar Cells</u>	
Silicon	0.3-0.7 (c)
Solder	2.5 (c)

(a) Value submitted by manufacturer.

(b) Cubical expansion: cm³/cm³/°C.

(c) Handbook of Chemistry and Physics;
Chemical Rubber Publication Company,
30th Edition (1947).

TABLE 3-7

Adhesive Cost for 5-Mil Glue Line

Adhesive	Cost (\$/lb)	Density (lb/in. ³)	Cost/Vol. (\$/in. ³)	Glue Line Cost (\$/ft ²)
. Epoxies				
Epon 828/Versamid	1.12	0.0425	0.048	0.034
Epon 828/HHPA	1.03	0.0425	0.044	0.032
. Silicones				
DC 732	3.75	0.037	0.138	0.099
GE 580	3.80	0.038	0.144	0.103
DC 280A	3.94	0.039	0.152	0.109

TABLE 3-8

Acrylic Molding Compounds

Manufacturer	Resin	Form	Chemistry	Specific Gravity	Process Temp. °C	Weather Prognosis (years)	\$/Lb	\$/Pt ² /Mil	Remarks
Rohm & Haas	Plexiglas: V-811	Pellets	MMA	1.19		15+	0.59	0.00365	
	V-415	Pellets	MMA	1.18			0.59	0.00362	
	V-044	Pellets	MMA	1.19	165	15+	0.59	0.00365	
	V-920	Pellets	MMA	1.19	160	15+	0.59	0.00365	
	VM	Pellets	MMA/EA	1.18	140	12-15	0.59	0.00362	
	VS	Pellets	MMA/EA	1.18	160	8-10	0.59	0.00362	
	VS-100			1.18			0.60	0.00368	
	V-100			1.18			0.60	0.00368	
	V-100-UVA7			1.18			0.83	0.00509	
	V-100-UVA5			1.18			0.62	0.00380	
	V-100-UVA8			1.18			0.83	0.00509	
	V-045	Pellets		1.19	165	15+	0.59	0.00365	
	V-052	Pellets		1.19		15+	0.61	0.00377	
	55	Sheet		1.19		15+	4.74/ ft ²	0.05925	80-mil sheet, cross-linked; military grade
	G	Sheet		1.19		20+	1.19/ ft ²	0.03967	30-mil sheet
	II-UVA	Sheet		1.19			1.82/ ft ²	0.03033	60-mil sheet; military grade
	I-A-UVA	Sheet		1.18	165		0.61	0.00374	
	I-A-UVT	Sheet		1.18	165		0.61	0.00374	
	UF-3	Sheet		1.19			2.44/ ft ²	0.0610	40-mil sheet
	UF-4	Sheet		1.19			2.44/ ft ²	0.0610	40-mil sheet
	K	Sheet		1.19			0.54/ ft ²	0.00675	80-mil sheet

...Continued

TABLE 3-8 (Continued - 2)

Manufacturer	Resin	Form	Chemistry	Specific Gravity	Process Temp. OC	Weather Prognosis (years)	\$/Lb	\$/Ft ² /Mil	Remarks
Rohm & Haas	Plexiglas: V-500	Pellets		1.15	165	5+	0.76	0.00454	
	V-066	Pellets	MMA/Rubber	1.19	165	15+	0.59	0.00365	
	DR	Pellets	MMA/Rubber	1.15	165	8-10	0.79	0.00472	
	DRM	Pellets		1.15	165	8-10	0.86	0.00514	
Rohm & Haas	Acryloid:								
	A-11	Powder	MMA	1.17			0.76	0.00462	
	A-21	Powder	MMA	1.12			1.11	0.00643	
	A-30	Powder	MMA	1.12			0.75	0.00434	
	B-48	Powder	MMA	1.12			1.18	0.00684	
	B-44	Powder	MMA Copolymer	1.12			0.98	0.00570	
	B-50	Powder	MMA Copolymer	1.12			1.06	0.00614	
	B-66	Powder	M/BuMA/Copoly.	1.09			0.81	0.00456	
	B-67	Powder	i-BuMA	1.05			1.20	0.00655	
	B-72	Powder	EMA Copolymer	1.15			1.17	0.00696	
	B-82	Powder	MMA Copolymer	1.16			0.78	0.00467	
	K-120N-D	Powder		1.18			0.633	0.00388	
	K-120N	Powder	88 MMA/12 EA	1.18			0.603	0.00370	
	K-147	Powder		1.10			0.693	0.00396	
	K-125	Powder		1.18			0.693	0.00425	
	K-175	Powder		1.05			0.713	0.00389	
	KP-708	Granules		1.10			1.32	0.00755	
	KM-611	Powder	MBS	1.00			0.64	0.00334	
	KM-641	Powder	MBS	1.10			0.71	0.00407	
	KM-323B	Powder	Graft on Acrylic Rubber	1.10			0.65	0.00373	
	KM-653	Powder		1.10			0.72	0.00413	
	KM-901	Powder	MBS	1.10			0.63	0.00362	

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TABLE 3-8 (Continued - 3)

Manufacturer	Resin	Form	Chemistry	Specific Gravity	Process Temp. °C	Weather Prognosis (years)	\$/Lb	\$/Ft ² /Mil	Remarks
Rohm & Haas ↓	Acryloid:								
	KM-607N	Powder	MBS	1.10			0.74	0.00425	
	KM-228	Powder		1.10			0.73	0.00419	
	KM-636	Powder		1.10			0.74	0.00425	
	KM-318P	Powder		1.10			0.67	0.00384	
DuPont ↓	KM-607	Powder		1.05			0.74	0.00405	
	Lucite:								
	40	Pellet/Bead	MMA Copolymer	1.18	157		0.65	0.00399	
	47	Pellet/Bead	MMA Copolymer	1.19	177		0.65	0.00402	
	4P	Beads	MMA	1.19			1.06	0.00656	
	29	Pellets	MMA Copolymer	1.18	157		0.65	0.00399	
	30	Pellets	MMA Copolymer	1.18	150		0.65	0.00399	
	41	Beads	MMA	1.18			1.06	0.00650	
	T-1000	Pellets		1.15			0.82		
	L	Cast Sheet					0.76/ft ²	0.01267	0.060" min. thickness
DuPont ↓	XL	Cast Sheet					0.76/ft ²	.01267	0.060", crosslinked
	Elvacite:								
	2008	Beads	MMA	1.19	90		0.85	0.00526	
	2009	Beads	MMA	1.15	68		0.80	0.00478	
	2010	Beads	MMA	1.20	88		0.76	0.00474	
	2041	Beads	MMA	1.20	90		1.14	0.00711	
	2028	Beads		1.14			1.29	0.00764	
	2013	Beads	M/n-BMA	1.15	77		0.83	0.00493	

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TABLE 3-8 (Continued - 4)

Manufacturer	Resin	Form	Chemistry	Specific Gravity	Process Temp. °C	Weather Prognosis (years)	\$/lb	\$/ft ² /mil	Remarks
DuPont	Elvacite:								
	2042	Beads	EMA	1.11	57		1.45	0.00836	
	2043	Beads	EMA	1.14	50		1.27	0.00752	
	2044	Beads	n-BMA	1.07	40		1.41	0.00784	
	2045	Beads	1-BMA	1.09	63		1.31	0.00742	
Cryo Industries	2046	Beads	n/1-BMA	1.09	52		1.31	0.00742	
	2021	Beads		1.14			0.87	0.00513	
	Acrylite:								
	H-15	Pellets	MMA/EA	1.18	207	20	0.59	0.00362	
	H-12	Pellets	MMA/EA	1.18	207	20	0.59	0.00362	
Cryo Industries	MP-10	Pellets	MMA/EA	1.12	221	<3	0.63	0.00364	
	MP-20	Pellets	MMA/EA	1.12	221		0.65	0.00375	
	MP-30	Pellets	MMA/EA	1.18	207	20	0.56	0.00353	
	GP	Cast sheet, shell				20	1.19/ft ²	0.01970	30-mil sheet
	FF	Cast sheet, continuous				20	0.49/ft ²	0.00613	80-mil sheet
Cryo Industries	Cryolite:								
	G-20	Pellets	MMA/Styrene/Rubber	1.11		10	0.61	0.00352	
	XT-250	Pellets	MMA/SAN/10% Rubber	1.12	190	10	0.57	0.00333	
Richardson Company	XT-375	Pellets	MMA/SAN/14% Rubber	1.10	246	10	0.59	0.00337	
	Richardson:								
	R-570	Pellets	S/MMA	1.13		1	0.49	0.00288	
	NAS	Pellets	S/MMA	1.09	54	1	0.48	0.00272	

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TABLE 3-8 (Continued - 5)

Manufacturer	Resin	Form	Chemistry	Specific Gravity	Process Temp. °C	Weather Prognosis (years)	S/Lb	S/Ft ² /Mil	Remarks
Richardson Company	Richardson: P-205-UV P-301 RTA	Pellets Pellets Pellets	S/MMA/UV 85 S/15 MMA S/MMA/Rubber	1.13 1.18 1.13	60	5 ~5	0.46 - 0.59	0.00270 - 0.00347	Experimental
Swedlow, Inc.	Swedlow S-350	Sheet	oriented MMA				(a) 4.58/ ft ²	0.16670	Identical to RPH Plexi- glas 55 (crosslinked)
Grow Chemical Corp.	Thermoset acrylic Series 1000	Powder		0.9	154				Heat curable
Sierracin	Sierracin S-100	Oriented Sheet	MMA	1.19					
Portin Plastics	Dynacrylic	Oriented Sheet	MMA						
Goodyear Aerospace	Thermoshield	Oriented Sheet	MMA				20.00	0.33	Rohm & Haas material oriented by Goodyear
Glidden-Durkee	710-6 Acrylic	Powder		1.05			2.15	0.01173	Thermoset; heat curable
Swedcast Corp.	Swedcast	Sheet	MMA				0.51/ ft ²	0.00638	0.080" thickness
Goodyear	Pilolite: AC AC-L HML VTAC VTAC-L	Granules Granules Granules Granules Granules	S/MMA S/MMA S/MMA VT/MMA VT/MMA	1.04 1.04 1.04 1.03 1.03	165 140 140 57 47				

VT = Vinyl toluene

(a) Approximately 10X stretched

TABLE 3-9

Acrylic Casting and Embedding Compounds

Manufacturer	Resin	Form	Chemistry	Specific Gravity	Process Temp. °C	Weather Prognosis (years)	\$/Lb	\$/Ft ² /Mil
Vernon-Benshoff	Klearmount	Syrup	MMA	1.19	RT (a)	15+	8.00	0.0490
Polysciences	3573 Embedding Media	Syrup	MMA/BMA	1.19	RT		7.44	0.0460
Polysciences	0849	Liquid	MMA	1.19	RT		3.30	0.0204
Polysciences	HH772	Syrup	-	1.19	RT		4.00	0.0247
DuPont	Lucite 4C							

(a) Cures in 70 minutes

TABLE 3-10

Solvent-Based Acrylic Coatings

Manufacturer	Coating	Percent Solids	Specific Gravity of Film (Dry)	T _g , °C	Thermoset; Curing Agent	\$/Lb	sq/Ft ² /Mil
Kohm & Haas	Acryloid:				Yes; Melamine		
	AT-400	80	1.10		No; -	0.26	0.00186
	A-101	40	1.10		No; -	0.49	0.00700
	A-10	30	1.10		No; -	0.65	0.01239
	A-21	30	1.10		No; -	0.42	0.00800
	A-21LV	30	1.10		No; -	0.44	0.00838
	B-44	40	1.10		No; -	0.43	0.00607
	B-48N	45	1.10		No; -	0.54	0.00680
	B-50	45	1.10		No; -	0.48	0.00610
	B-66	50	1.09		No; -	0.49	0.00610
	B-78	45	1.05		No; -	0.60	0.00628
	B-67MT	45	1.05		No; -	0.60	0.00728
	B-72	50	1.15		No; -	0.61	0.00729
	B-82	50	1.16		No; -	0.46	0.00555
	B-84	45	1.10		No; -	0.60	0.00762
	B-99	50	1.10		No; -	0.56	0.00640
	C-10LV	40	1.10		No; -	0.76	0.01086
	F-10	40	1.10		No; -	0.51	0.00729
	NAD-10	40	1.10		No; -	0.68	0.00965
	AT-50	50	1.10		Yes; Self-cure	0.66	0.00755
	AT-51	50	1.10		Yes; Self-cure	0.53	0.00606
	AT-56	50	1.10		Yes; Amine	0.50	0.00572
	AT-70	50	1.10		Yes; Epoxy	0.56	0.00635

...Continued

TABLE 3-10 (Continued - 2)

Manufacturer	Coating	Percent Solids	Specific Gravity of Film (Dry)	T _g , °C	Thermoset; Curing Agent	\$/Lb	\$/ft ² /Mil
Rohm & Haas ↓	Acryloid:						
	AT-71	50	1.10		Yes; Epoxy	0.51	0.00583
	AT-75	50	1.10		Yes; Epoxy	0.56	0.00635
	AT-63	50	1.10		Yes; -	0.50	0.00572
	AT-64	50	1.10		Yes; -	0.51	0.00583
	Au-608	60	1.10		No; -	0.74	0.00705
	B-7	20	1.10		No; -	0.68	0.01943
	C-10	20	1.10		No; -	0.99	0.02830
	CS-1	83	1.10		No; -	0.93	0.00640
	P-89	60	1.10		No; -	0.65	0.00615
Conchemco ↓	OL-42	80	1.10		No; -	0.91	0.00650
	RAS-75	86	1.10		No; -	1.06	0.00726
	WR-97	70	1.10		No; -	0.69	0.00564
	Acrylic Resin:						
	311-104		1.12				
Goodrich ↓	311-405		1.12				
	311-121		1.12				
	311-120		1.12				
	Carboaset:						
	514A	70	1.12	55	Yes; Epoxy amine	1.04	0.00865
	XL-11	30		26		Experimental	Experimental
	XL-19	40					

...Continued

TABLE 3-10 (Continued - 3)

Manufacturer	Coating	Percent Solid	Specific Gravity of Film (Dry)	T _g , °C	Thermoset; Curing Agent	\$/Lb	\$/ft ² /Mil
Ashland Chemical	Aeroseal: 41-10X60 41-20-XB50	60	1.13		Yes; Melamine	0.51	0.00494
		50	1.14		Yes; Melamine	0.52	0.00610
MR Plastics and Coatings	Mistacote: 127-F (a) 125-F	20			No; -		
		19			No; -		

(a) Good adhesion to aluminum

TABLE 3-11

Solvent Acrylic Adhesives

Manufacturer	Material	Percent Solids	Specific Gravity (Dry)	Thermo-set	Curing Agent	\$/lb	\$/Ft ² /Mil
Monsanto	GMS-270	55	1.15	Yes	Self-Cure	0.56	0.00609
	GMS-264	55	1.15			0.54	0.00587
	RA-2107	34	1.00			0.64	0.00978
	RA-2165	34	1.00	Yes	Self-Cure	0.67	0.01024
	GMS-263	44.5	1.15	Yes	Self-Cure (a)	0.70	0.00940
	GMS-276	40	1.15	Yes	Epoxy or Amine (a)	0.75	0.01121
	GMS-387	30	1.15	Yes	Self-Cure	0.65	0.01295
	RA-784	40	1.05	Yes	Self-Cure (a)	0.66	0.00900
	RA-788	40	1.05	Yes	Epoxy or Amine (a)	0.65	0.00887
	RA-737	30	1.05	Yes	Self-Cure	0.65	0.01182
	RA-1151	40	1.10	Yes	PAPI only	0.68	0.00972
	RA-1159	34	1.10	Yes	Self-Cure (a)	0.64	0.01076
	RA-1160	56	1.15	Yes	Epoxy or Amine	0.61	0.00651
	RA-1678	40	1.15	Yes	Self-Cure	0.59	0.01031
	RA-1725	32.5	1.10	Yes	Self-Cure	0.59	0.01038
	RA-1753	31	1.10	Yes	Self-Cure	0.62	0.01143
	RA-1822	34	1.10			0.69	0.01160
	RA-1892	34	1.15			0.70	0.01231
	RA-1896	36	1.15	Yes	Epoxy or Amine	0.61	0.01013
	RA-2018	40	1.15	Yes	Self-Cure	0.61	0.00911
	RA-2102	45	1.16			0.68	0.00911
Kodak	HE-100B	100	1.10	Yes	-	50.00	0.2858
	HE-100X	100	1.10	Yes	-	50.00	0.2858

(a) Catalyst suggested

...Continued

TABLE 3-11 (Continued - 2)

Manufacturer	Material	Percent Solids	Specific Gravity (Dry)	Thermo-set	Curing Agent	\$/Lb	\$/Ft ² /Mil
Rohm & Haas	Acryloid:						
	B-82	50	1.16	No	-	0.46	0.00555
	B-72	50	1.15	No	-	0.61	0.00729
	C10-LV	40	1.10	No	-	0.76	0.01086
	F-10	40	1.10	No	-	0.51	0.00729
	NAD-10	40	1.10	No	-	0.68	0.00965
	AT-63	50	1.10	Yes	-	0.50	0.00572
	AT-64	50	1.10	Yes	-	0.51	0.00583
BASF	Acronal:						
	3L	50	1.15	No	-	0.95	0.01136
	4F	50	1.14			1.24	0.01469
	500L	40	1.10			1.02	0.01458
	700L	50	1.10			1.05	0.01201
Goodyear	Pliobond 8004	36	1.09	Yes	Self-Cure	0.73	0.01149

TABLE 3-12

Acrylic Latex Adhesives and Coatings

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T _g (°C)	Thermoset; Curing Agent	\$/Lb	\$/Ft ² /Mil
B. F. Goodrich	Hycar:							
	2600X83	Anionic	52	1.13	-15	Yes; Self-Cure	0.51	0.00576
	2600X84	Anionic	50	1.14	8	Yes; Self-Cure	0.54	0.00634
	2600X91	Anionic	50	1.13	20		0.54	0.00634
	2600X92	Anionic	50	1.12	-12	Yes; Self-Cure	0.54	0.00623
	2600X94	Anionic	50	1.13			0.56	0.00652
	2600X104	Anionic	50	1.12	-15	Yes; Self-Cure	0.52	0.00605
	2600X106	Anionic	50	1.10	29	Yes; Self-Cure	0.54	0.00617
	2600X112	Anionic	50	1.13	29	Yes; Self-Cure	0.55	0.00646
	2600X120 (a)	Anionic	50	1.14	-11	Yes; Self-Cure	0.53	0.00622
	260X138	Anionic	50	1.14	25		0.56	0.00658
	2671	Anionic	52	1.13	-11	Yes; Self-Cure	0.58	0.00649
	2679	Anionic	48	1.12	-3	Yes; Self-Cure	0.53	0.00643
	2679X6	Anionic	48	1.10	-3	Yes; Self-Cure	0.58	0.00690
	2600X137	Anionic	50	1.13	-18	Yes; Self-Cure	0.56	0.00658
	2600X146	Anionic	50	1.13	-55	Yes; Self-Cure	0.99	0.01163
	2600X171	Anionic	48	1.06	45	Yes; Self-Cure	0.56	0.00643
	2600X172	Anionic	50	1.10	33	Yes; Self-Cure	0.57	0.00651
	2600X178	Anionic	51	1.13			0.58	0.00662
	2600X189	Anionic	51	1.11	-32	Yes; Self-Cure	0.60	0.00679
	2600X205	Anionic	49	1.13	-43	Yes; Self-Cure	0.68	0.00851
	2600X207		50	1.13	-39		0.68	0.00799
	2600X208		50	1.13			0.56	0.00652

(a) Special

...Continued

TABLE 3-12 (Continued - 2)

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T _g (°C)	Thermoset; Curing Agent	\$/Lb	\$/Ft ² /Mil
B. F. Goodrich	Hycar:							
	2600X210 (a)							
	2600X222	Anionic	50	1.14	-20	Yes; Self-Cure	0.56	0.00664
	2600X223		49	1.13	-50		0.99	0.01186
			50	1.13	-20		0.66	0.00775
Kolon & Haas	2600X237		50	1.21	76		0.62	0.00780
	2600X238		50	1.13			0.66	0.00775
	2600X255		50	1.13			0.54	0.00628
	2600X256	Anionic	50	1.20	45		0.62	0.00773
	Rhoplex:							
	AC-22	Nonionic	44.5	1.15	-27	No; -	0.24	0.00322
	AC-33	Nonionic	46.5	1.15	-27	No; -	0.26	0.00334
	AC-73	Nonionic	46.5	1.15	2	No; -	0.33	0.00479
	B-60A	Nonionic	46.5	1.15	-27	No; -	0.27	0.00344
	AC-234	Nonionic	46.5	1.15	-23	No; -	0.28	0.00353
	AC-61	Anionic	46.5	1.15	-17	No; -	0.31	0.00395
	N-580	Anionic	55	1.5	-85	No; -	0.42	0.00455
	N-619	Anionic	57	1.15	-75	No; -	0.48	0.00503
	HA-4	Nonionic	45	1.15	-62	Yes; -	0.33	0.00438
	B-5	Nonionic	46	1.15	-59	Yes; -	0.54	0.00702
(a) Special	B-10	Nonionic	46	1.15	-52	Yes; -	0.38	0.00491
	B-15	Nonionic	46	1.15	-49	Yes; -	0.27	0.00354
	LC-40	Anionic	55	1.15	-49	Yes; -	0.37	0.00397
	N-495	Anionic	57	1.15	-48	Yes; -	0.42	0.00440
	K-14	Nonionic	46	1.15	-92	Yes; Self-Cure	0.35	0.00458

...Continued

TABLE 3-12 (Continued - 3)

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T _g (°C)	Thermoset; Curing Agent	\$/lb	\$/ ² /Mil
Rohm & Haas	Rhoplex:							
	K-3	Nonionic	46	1.15	-77	Yes; Self-Cure	0.29	0.00380
	K-87	Nonionic	46	1.15	-63	Yes; Self-Cure	0.35	0.00448
	HA-8	Nonionic	46	1.15	-59	Yes; Self-Cure	0.27	0.00354
	HA-24	Anionic	44.5	1.15	-52	Yes; Self-Cure	0.27	0.00366
	E-32	Nonionic	46	1.15	-47	Yes; Self-Cure	0.27	0.00344
	E-358	Nonionic	60	1.15	-45	Yes; Self-Cure	0.38	0.00376
	E-269	Anionic	46	1.15	-38	Yes; Self-Cure	0.30	0.00393
	RA-90	Nonionic	46	1.15	-33	Yes; Self-Cure	0.30	0.00387
	HA-12	Nonionic	45	1.15	-28	Yes; Self-Cure	0.26	0.00342
	HA-20	Anionic	45.5	1.15	-16	Yes; Self-Cure	0.39	0.00506
	HA-16	Nonionic	46	1.15	-12	Yes; Self-Cure	0.27	0.00354
	TR-520	Nonionic	50	1.15	-53	Yes; Self-Cure	0.30	0.00361
	LC-45	Anionic	65	1.15	-10	Yes; -	0.47	0.00432
	TR-440	Nonionic	46.5	1.15	-59	Yes; Self-Cure	0.35	0.00447
	TR-485	Nonionic/ Anionic	50	1.15	-91	Yes; Self-Cure	0.41	0.00487
	MV-1	Anionic	46	1.15		No; -	0.36	0.00461
	MV-2		46	1.15			0.34	0.00448
	MV-9		45.5	1.15			0.38	0.00499
	MV-17		45	1.15			0.37	0.00485
	N-560		57	1.15			0.45	0.00467
	P-50		43	1.15			0.34	0.00476
	P-64		45.5	1.15			0.30	0.00392
	P-376		50	1.15			0.33	0.00389
	P-491		46	1.15			0.28	0.00364

...Continued

TABLE 3-12 (Continued - 4)

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T _g (°C)	Thermoset; Curing Agent	\$/Lb	\$/Ft ² /Mil
Rohm & Haas	Rhoplex:							
	PR-26		30.5	1.15			0.54	0.01048
	R-47		40	1.15			0.27	0.00403
	TR-96		44.5	1.15			0.37	0.00493
	TR-653		35	1.15			0.26	0.00446
	TR-908		50.5	1.15			0.32	0.00382
	TR-914		50	1.15			0.29	0.00341
	TR-934		44.5	1.15			0.28	0.00369
	WN-80		40	1.15			0.35	0.00527
	B-85	Anionic	38	1.15	55	No; -	0.29	0.00507
	AR-74	Anionic	45	1.15	-4	No; -	0.23	0.00345
	SS-521	Nonionic	50	1.15	10	No; -	0.41	0.00554
	WL-91		41.5	1.15		No; -		
	AC-19		44.5	1.15			0.23	0.00309
	AC-25		46.5	1.15			0.28	0.00353
	AC-64		60.5	1.15			0.35	0.00341
	AC-172		45	1.15			0.37	0.00491
	AC-201	Nonionic	45.6	1.15		Yes; Self-Cure	0.44	0.00570
	AC-235		46.5	1.15			0.25	0.00369
	AC-388		50	1.15			0.29	0.00350
	AC-490	Nonionic	46	1.15		No; -	0.27	0.00351
	AC-507		47	1.15		No; -	0.30	0.00375
	AC-604		46	1.15			0.42	0.00546
	AC-634		46.5	1.15			0.29	0.00366
	AC-635		46.5	1.15			0.30	0.00382
	AC-658		47	1.15			0.39	0.00496

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TABLE 3-12 (Continued - 5)

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T _g (°C)	Thermoset; Curing Agent	\$/Lb	\$/Ft ² /Mil
Rohm & Haas ↓	Rhoplex:							
	AC-707		65	1.15			0.37	0.00340
	AC-1084		50	1.15			0.37	0.00442
	B-58		32	1.15			0.54	0.01004
	B-74		38	1.15			0.32	0.00503
	B-88		42.5	1.15			0.30	0.00472
	B-89A	Nonionic	35	1.15		Yes; Self-Cure	0.35	0.00602
	B-413		39	1.15			0.34	0.00535
	B-505	Anionic	40	1.15		Crosslinked	0.31	0.00456
	B-654		40	1.15			0.34	0.00508
	B-832		40	1.15			0.30	0.00441
	B-924		38	1.15			0.23	0.00362
	CA-12		53.5	1.15			0.41	0.00452
	E-330		47	1.15			0.31	0.00394
	LC-67		65	1.15			0.49	0.00451
	MC-76		47	1.15			0.31	0.00394
B. F. Goodrich ↓	Acrysol:							
	WS-12		~30	1.15	~37	Yes; Amines	0.32	0.00628
	WS-24		36	1.15	39	Yes; Amines	0.36	0.00589
	Experimental Emulsion E-15	Anionic	54	1.15	-49	Yes; -		
	Hycar:							
	2600X257		50	1.13			0.55	0.00640
	2671X 20		50	1.13			0.55	0.00646

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TABLE 3-12 (Continued - 6)

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T _g (°C)	Thermoset; Curing Agent	\$/Lb	\$/Ft ² /Mil
B. F. Goodrich ↓	Hycar:							
	2671X22		50	1.13			0.53	0.00623
	2671X23		50	1.13			0.54	0.00634
	2679X22		62	1.13			0.56	0.00530
Staley Chemical Co. ↓	Ubatol:							
	U-3045			1.15				
	U-3050			1.15				
	U-3054		40	1.15	23.5		0.25	0.00037
	U-3101	Anionic	40	1.15			0.26	0.00381
	U-3400	Anionic	40	1.15				
	U-3406		40	1.15			0.20	0.00296
	U-3500			1.15				
	U-3215	Anionic	40	1.15			0.28	0.00411
National Starch ↓	X-Link:							
	2802	Anionic	45	1.19	29	Yes; Self-Cure	0.23	0.00316
	2813	Anionic	45	1.16	-2	Yes; Self-Cure	0.30	0.00402
	2833	Anionic	45	1.13	-29	Yes; Self-Cure	0.28	0.00362
	2873	Anionic	45	1.16	-36	Yes; Self-Cure	0.29	0.00389
Celanese	CL-300	Nonionic	46	1.15				
Johnson Wax ↓	Joncryl:							
	74 M73 (b)		49 50	1.14			0.43	0.00520

(b) Custom formulation (not commercial)

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TABLE 3-12 (Continued - 7)

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T _g (°C)	Thermoset; Curing Agent	\$/Lb	\$/Ft ² /Mil
Polyvinyl Chemical	Neocryl:							
	A601		32	1.12		Yes; Amine	0.39	0.00700
	A604		32	1.12		Yes; Amine	0.44	0.00800
	A620		40	1.12		Yes; Amine	0.36	0.00517
	A621		40	1.15		Yes; Amine	0.36	0.00530
Union Carbide	Ucar:							
	130	Nonionic	58	1.2	43	No; -		
	131	Nonionic	60	1.15	26	No; -		
	150	Nonionic	58	1.2	37	No; -		
	151	Nonionic	60	1.12	24	No; -		
	152	Anionic	58	1.12	-7	Yes; -		
	153	Anionic	55	1.12	-2	Yes; -		
	154	Anionic	60	1.14	0	Yes; -		
	163	Anionic	58	1.12	-5	No; -		
	167	Anionic	63	1.15	23	No; -		
	380	Nonionic	48	1.14	17	No; -		
	865	Anionic	55	1.14	5	No; -		
	872		58	1.12	-7	No; -		
	874		60	1.14	-1	No; -		
	878		61	1.14	10	No; -		
	1248		50					
	4312	Anionic	45	1.1	23	No; -		
	4358	Anionic	45		25	No; -		
	4510	Anionic	43	1.13	44	Yes; -		
	4550	Anionic	45	1.13	39	Yes; -		
	508		53		20			
	4341	Anionic	45.5	1.04	10	No; -		

...Continued

TABLE 3-12 (Continued - 8)

Manufacturer	Material	Latex Type	Percent Solids	Specific Gravity (Dry)	T _g (°C)	Thermoset; Cu. 'ng Agent	\$/Lb	\$/Ft ² /Mil
Union Carbide	Ucar:							
	165	Anionic/Nonionic	55	1.15	28	No; -		
	166		55	1.15	22	No; -		
	360		55	1.16	27	No; -		
	365		55	1.15	28	No; -		
	366		55	1.15	23	No; -		
	366HS		64	1.15	23	No; -		
	4150		55	1.15	28	No; -		
	4362		48	1.12	16	No; -		
	5000		55	1.15	5	No; -		

TABLE 3-13

Bulk and Hot-Melt Acrylic Adhesives

A - Bulk Acrylic Adhesives

Manufacturer	Material	Cure Cycle	Clarity	Density (g/cc)	\$/Lb	\$/Ft ² /Mil
Hughson	Versilok: 501 502 503 505 506 510 513 516 520 521 522 528 540 541 580	10 min/RT, Activator	Hazy	1.1	1.65	0.00943
Loctite	306 307 308 310 X353	3 min/120°C, Activator ↓ UV, Activator	Clear	1.1 ↓ 1.15	16.48 15.66 15.66 15.66 15.77	0.09421 0.08952 0.08952 0.08952 0.09425
Eastman	910 910FS 910EM 910ET	RT	Clear	1.1 ↓	51.75	0.2960

...Continued

RT = Room Temperature

TABLE 3-13 (Continued - 2)

Manufacturer	Material	Cure Cycle	Clarity	Density (g/cc)	\$/Lb	\$/Ft ² /Mil
Eastman Kodak ↓	Optical:					
	HE-2	24 hr/60°C	Clear	1.10	58.00	0.3315
	HE-80	8 hr/60°C	↓	↓	78.00	0.4459
	HE-S-1	8 hr/60°C			58.00	0.3316
	HEP-4	8 hr/60°C			58.00	0.3316
	HE104-2	16 hr/60°C	↓		48.00	0.2744
Daubert	R-324-124A	UV/RT, Activator	Clear			
	Melacril 5071	RT, Activator	Clear	1.05	2.20	0.01200
Oxo	DAC	UV	Clear	1.02	40.00	0.2120
	DSP	UV	Clear	1.05	40.00	0.2183
E. P. Goodrich ↓	Tame:					
	200	24 hr/RT, Activator	Hazy	1.1	1.49	0.00852
	210	↓	↓	↓	↓	↓
	212					
	232					
	250		Clear			
Hen Adhesives ↓	TESA-561-2	15-20 min./RT, Activator	Clear	0.98	2.56	0.013
	TESA-561-6	↓	↓	↓	↓	↓
	TESA-561-17					
	TESA-561-18					

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TABLE 3-13 (Continued - 3)

Manufacturer	Material	Cure Cycle	Clarity	Density (g/cc)	\$/lb	\$/Ft ² /Mil
National Starch	Weld Master 1	6-8 min / RT	Clear	1.0	3.65	0.0190
	Weld Master 2	6-8 min / RT	Clear	1.0	3.65	0.0190
	Weld Master 3	6-8 min / RT	Clear	1.0	3.65	0.0190
Vigor	Alpha-Ethyl	1 min / RT	Hazy	1.1	61.20	0.3499
	Alpha-Methyl	1 min / RT	Hazy	1.1	61.20	0.3499
Tracon	Trabond 2190		Hazy	1.1	107.00	0.6117
Emerson & Cuming	Eccobond KWIK	30 sec/RT	Clear	1.0	91.93	0.4778
Devcon	Zip Grip 10	30 sec/RT	Clear	1.0	67.50	0.3508
H. B. Fuller	RA 0018	8 min/RT, Activator		1.1	3.50	0.0200
Bostik	M 890			1.1		

B - Hot-Melt Acrylic Adhesives

Manufacturer	Material	Specific Gravity	Process Temp. °C	Weather Prognosis (years)	\$/lb	\$/Ft ² /Mil	Remarks
Daubert	R-246-57M 329-002	1.10		3-4 3-4	0.90	0.00515	Clear; yellow Clear; brown
Williamson	6842	1.15	180		2.75	0.01644	Clear; brown
BASF	Acronal-4	1.10			1.24	0.00709	
Rohm & Haas	QR-667	1.10			1.40	0.0080	Transparent; yellow

TABLE 3-14

Plastic Based Substrate Materials

Manufacturer	Material	Grade	Form	Flexural Modulus (psi x 10 ⁵)		Density (g/cc)	Price		Avg. Cost/ Volume (\$/in. ³)	Minimum Thickness Required (in.)	Required Volume (in. ³)	Minimum Module Cost (\$/ft. ²)
				Length- wise	Cross- wise		\$/Lb	\$/ft. ²				
LNP	HDPE Fiberglass reinforced 20% Fiberglass 40% Fiberglass	FF-1004 FF-1008	Pellet Pellet	6.0 11.0		1.10 1.28	0.61 0.69	- -	0.0242 0.0318	0.250 0.204	36.0 29.4	0.87 0.93
LNP	HDPE Glass bead filled 20% Glass 40% Glass	FB-1004 FB-1008	Pellet Pellet	3.4 3.9		1.10 1.28	0.61 0.69	- -	0.0242 0.0318	0.250 0.204	36.0 29.4	0.87 0.93
Primex	Acrylic Honeycomb	Prime-Cor- X-Lucite	4mm Sheet	(a)		0.28 lb/ft. ³	-	0.60	0.0265			
Voltek	Polyethylene foam	R300	1" Sheet	(a)		2.4-4.0 lb/ft. ³	-	1.50	0.0104			
Norfield	Polycarbonate Honeycomb	NorCore	1" Sheet	(a)			-	0.85	0.0059			
Norfield	Impact Styrene Honeycomb	NorCore	1" Sheet	(a)			-	0.55	0.0038			
Rohm & Haas	Acrylic	V-811	Pellet	3.0		1.2	1.42	-	0.0391	0.315	45.3	1.77
General Electric	Polycarbonate	Lexan 123	Pellet	3.2		1.2	1.84	-	0.077	0.308	44.3	3.41
Monsanto	Polystyrene	Lustran	Pellet	2.1		1.08	0.38	-	0.0142	0.355	51.1	0.725

(a) These are structural materials that demonstrate only apparent modulus.

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TABLE 3-14 (Continued - 2)

Manufacturer	Material	Grade	Form	Flexural Modulus (psi x 10 ⁵)			Density/ (g/cc)	Price		Avg. Cost/ Volume (\$/in. ³)	Minimum Thickness Required (in.)	Required Volume (in. ³ /ft ²)	Minimum Module Cost (\$/ft ²)
				Length- wise	Cross- wise			\$/lb	\$/ft ²				
Hukcross	Polyurethane foam, rigid	-	Foam		0.5		0.32	0.77	-	0.0089	0.572	82.4	0.73
Pohm & Haas	Polycarbonate Honeycomb	Tuffak			3.2(a)		0.16	4.40	-	0.0252	0.308	44.3	1.56
Synthane Taylor	Paper-based phenolic laminate	X, 1/16"	Sheet	18.0	13.0		1.36	1.00	0.46	0.0490	0.182	26.2	1.28
Synthane Taylor	Fabric-based phenolic laminate	C, 1/16"	Sheet	10.0	9.0		1.36	2.07	0.94	0.1016	0.214	30.8	3.13
Synthane Taylor	Glass-reinforced melamine laminate	G-9	Sheet	25.0	20.0		1.90	2.90	-	0.1988	0.161	23.1	4.59
Synthane Taylor	Glass-reinforced epoxy laminate	G-10	Sheet	27.0	22.0		1.80	3.07	-	0.1994	0.156	22.5	4.48
Synthane Taylor	Glass-reinforced epoxy laminate	PB-400	Sheet	27.0	22.0		1.80	2.10	-	0.1364	0.156	22.5	3.07
Kalval	Polyester Fiberglass laminate	1.16" 1/8"	Sheet		10.0		1.45	-	0.52 0.85	0.0472	0.210	30.2	1.42
Arco Polymer	Glass-reinforced styrene-maleic copolymer	Dylark 238 P20	Compound	7.2	4.1		1.22	0.46	-	0.0202	0.255	36.7	0.74
Arco Polymer	Styrene-maleic copolymer	Dylark 238	Compound		4.6		1.08	0.35	-	0.0136	0.273	39.3	0.53

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TABLE 3-14 (Continued - 3)

Manufacturer	Material	Grade	Form	Flexural Modulus (psi x 10 ⁵)		Density (g/cc)	Price		Avg. Cost/ Volume (\$/in. ³)	Minimum Thickness Required (in.)	Required Volume (in. ³ /ft. ²)	Minimum Module Cost (\$/ft. ²)
				Length- wise	Cross- wise		\$/lb	\$/ft. ²				
Arco Polymer	Structural foam, by Carbide Process	Dylark 238 P20, 1/4"	Sheet	5.3		0.8	-	0.64	0.0177	0.260	37.4	0.66
Fiberite	BMC (Bulk Molding Compound)	S-660B	Compound	15.0		1.8	0.65	-	0.0422	0.184	26.5	1.12
Fiberite	B-stage dry polyester molding compound	S-6414	Compound	15.0		1.8	1.30	-	0.0844	0.184	26.5	2.23
Fiberite	Short glass fiber reinforced phenolic molding compound	PM-4007	Compound	25.0		1.75	0.85	-	0.0536	0.155	22.3	1.17
ICC Primex	High-impact polystyrene		Sheet	2.7		1.04	0.45	-	0.0168	0.326	46.9	0.79
American Hoechst	Rigid vinyl		Sheet	4.7		1.4	2.00	-	0.1010	0.271	39.0	3.94
Hercules	Polypropylene homo- polymer with 40% talc	65P4-4	Compound	5.5		1.22	0.32	-	0.0140	0.257	37.0	0.52
Hercules	Polypropylene homo- polymer with 40% CaCO ₃	65P5-4	Compound	4.0		1.22	0.31	-	0.0136	0.286	41.1	0.56
Hercules	Polypropylene copoly- mer with 40% talc	75P4-4	Compound	5.0		1.22	0.33	-	0.0145	0.265	38.2	0.55
Hercules	Polypropylene copoly- mer with 40% CaCO ₃	75P5-4	Compound	4.0		1.22	0.34	-	0.0149	0.286	41.2	0.61

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TABLE 3-14 (Continued - 4)

Manufacturer	Material	Grade	Form	Flexural Modulus (psi x 10 ⁵)		Density (g/cc)	Price		Avg. Cost/ Volume (\$/ln ³)	Minimum Thickness Required (in.)	Required Volume (ln ³ /ft ²)	Minimum Module Cost (\$/ft ²)
				Length- wise	Cross- wise		\$/lb	\$/ft ²				
Hercules	Polypropylene structural foam	Med. impact copolymer 1/4"	Sheet	1.07		0.67	0.65	-	0.0157	0.444	63.9	1.00
Hercules	Polypropylene structural foam - 30% coupled Fiberglas	PC-012	1/4" Sheet	4.33		0.75	0.60	-	0.0216	0.278	40.0	0.86
Goodrich	Rigid PVC pipe compound	85781 85707	Compound	Tensile Modulus 4.2 4.6		1.40 1.40	0.31 0.30	-	0.0156 0.0151	0.281 0.273	40.5 39.3	0.63 0.59
Goodrich	PVC pipe compound	3007	Compound	4.26		1.55	0.79	-	0.0441	0.280	40.3	1.78
Premix	Polyester sheet molding compound	1222	Compound	15.0		1.85	0.61	-	0.0407	0.184	26.5	1.08
Ferro	Epoxy prepreg	E-293	10-mil Sheet	33.0		1.80	-	0.34	0.2361	0.141	20.3	4.79
Mastic (Valley Building Products)	Vinyl siding, 0.046" thick, for home exteriors		Sheet	4.0		1.46	-	0.45	0.0679	0.286	41.2	2.87
Fiberite	Melamine:											
	Glass filled Cellulose filled	M2037 M2014	Compound	27.0 19.0		1.95 1.47	1.40 1.24	-	0.0986 0.0658	0.151 0.170	21.7 24.5	2.13 1.61

TABLE 3-15

Metal Substrate Materials

Manufacturer	Material	Grade	Form	Flexural Modulus (psi x 10 ³)		Density (g/cc)	Price		Avg. Cost/ Volume (\$/in ³)	Minimum Thickness Required (in.)	Required Volume (in ³ /ft ²)	Minimum Module Cost (\$/ft ²)
				Length- wise	Cross- wise		\$/Lb	\$/Pt ²				
Armco	Galvanized steel	Roofing stock, 80-gage	Coil: 25-mil 50-mil 150-mil	300		7.8	-	0.21	0.058	0.068	9.79	0.56
							-	0.42				
Republic	Aluminum-coated steel	26-gage 1.5-mil coat	Sheet: 25-mil 40-mil	300	300	7.8	-	0.25	0.104	0.068	9.79	1.02
							-	0.60				
Republic	Painted steel	26-gage	40-mil Sheet	300		7.8	-	0.60	0.104	0.068	9.79	1.02
Republic	PVC-coated steel	26-gage	40-mil Sheet	300		7.8	-	0.80	0.138	0.068	9.79	1.35
Alcan	Aluminum	5052H32; H34	25-mil Sheet	100		2.6	0.84	-	0.079	0.098	14.1	1.11
Hamden	Aluminum	11H14; 5052H14	20-mil Sheet	100		2.6	0.85	-	0.079	0.098	14.1	1.11
Alcan	Anodized aluminum	Anodized film: 1-mil 1.5-mil	Coil: 25-mil 25-mil	100		2.6	0.95	-	0.094	0.098	14.1	1.32
Numerous	Stainless steel	316	Sheet	300		7.8	1.13	-	0.323	0.068	9.79	3.16
Numerous	Mild steel, hot-rolled		Sheet	300		7.8	0.15	-	0.043	0.068	9.79	0.42
Ferro	Porcelainized Steel	4-mil ground coat	Sheet	300		(b)		(a)	0.06	0.068	10.9	0.66

(a) Cost of 4-mil ground coat, both sides, approximately \$0.24

(b) Enamel density alone, 2.7

TABLE 3-16

Ceramic Based Substrate Materials

Manufacturer	Material	Grade	Form	Flexural Modulus (psi x 10 ⁵)		Density (g/cc)	Price		Avg. Cost/ Volume (\$/in. ³)	Minimum Thickness Required (in.)	Required Volume (in. ³)	Minimum Module Cost (\$/ft ²)
				Length- wise	Cross- wise		\$/Lb	\$/ft ²				
American Colloid	Bentonite/Paper	-	1/2" Sheet	(a)			-	0.35	0.0048	(a)		(a)
Resin Coated Sand Company	Foundry sand/phenolic	Casting powder	Powder	(a)		2.8	0.03	-	0.0030	(a)		(a)
Unesco	Acrylic latex modified Portland cement on plywood base.	Stone Panels	1" Sheet	> 5	(b)	2.5	-	2.00	0.0140	-	-	2.00 (b)
Silbroad	Same - 13% Latex	Floor leveling compound	Powder	> 5	(b)	2.5	0.19	-	0.0170	0.75 (b)	108 (b)	1.83 (b)
Crossfield	Neoprene-latex elasticized aluminum cement	Floor leveling compound	Powder	> 5	(b)	2.5	-					
Volary	Glass-reinforced gypsum (coated)	1" thick panel	Panel	10 Equivalent		1.7		0.30	0.0021	1.00 (b)	144 (b)	0.30 (b)
U.S. Gypsum	Glass-reinforced gypsum (uncoated)	Fabricated, 0.1" thick	Sheet	10 Equivalent		1.7		0.12	0.0083			(c)
PPG	Soda-lime glass	Float	Sheet	100		2.24	0.23	-	0.0208	0.098	14.1	0.29

(a) Very low elastic limit; unusably brittle (b) Estimated (c) Water-soluble; unusable

TABLE 3-17

Wood Product Substrates

Manufacturer	Material	Grade	Form	Flexural Modulus (psi x 10 ⁵)		Density	Price		Avg. Cost/ Volume (\$/in ³)	Minimum Thickness Required (in.)	Required Volume (in ³ /ft ²)	Minimum Module Cost (\$/ft ²)
				Length- wise	Cross- wise		\$/Lb	\$/ft ²				
Champion	Plywood	1/4" AC (a) 3/8" AC	4' x 8' Sheet	10			-	0.25 0.34	0.0063	0.21	30.2	0.19
Potlatch	Plywood	1/2" Sheeting (b) 1/2" Sanded	4' x 8' Sheet	10			-	0.22 0.30	0.0042	0.21	30.2	0.13
Plywood Association	Fiberglass/plastic- covered plywood	1/4", with 3/16" FRP 3/8", with 3/16" FRP	Sheet	30			-	0.50 0.70	Avg. 0.0082	0.15	21.6	0.18
Plywood Association	Kraft paper covered plywood	High-density overlay plywood, 1/4" thick Same, 3/8" thick	Sheet				-	0.33 0.46				
Roadman	Particle board, Phenolic binder	3/4" thick 3/8" thick	4' x 8' Panel	5		62 lb/ft ³	-	0.33 0.16	0.0030 0.0029	0.27 0.27	38.1 38.1	0.12 0.11
Roadman	Regular, urea resin binder	3/8" thick	4' x 8' Panel	5		62 lb/ft ³	-	0.19	0.0035	0.27	38.1	0.13
Blandin	Particle Board Segments 1"-1-1/2" large; phenolic binder.	1/4" thick 3/4" thick	4' x 8' Panel 8' x 28' Panel	5			-	0.13 0.40	0.0036 0.0637	0.27 0.27	38.1 38.1	0.14 0.14
Potlatch	Oriented flake- board; phenolic binder.		Sheet	5						0.26	38.1	
Masonite	Masonite, Fiber board	No. 1 Siding	7/16" Sheet	3.5		1.5 lb/ft ²	-	0.27	0.0043	0.30	43.0	0.19

(a) A-face with C-backing (suggested for outdoor use).

(b) C-face with D-backing (not weatherable).

TABLE 4-1

UV Stabilizers

Trade Name	Chemical Name	Function	Manufacturer	Price (\$/Lb)
. Benzophenones -				
Uvinul 400	2,4-dihydroxy benzophenone	UV absorber	GAF	6.70
Uvinul D-49	2,2'-dihydroxy-4,4'-dimethoxy benzophenone	UV absorber	GAF	12.40
Cyasorb UV-531	2-hydroxy-4-n-octoxy-benzophenone	UV absorber	American Cyanamid	4.80
Permasorb-MA	2-hydroxy-4-(2-hydroxy-3-methacrylyloxy)-propoxy-benzophenone	UV absorber	National Starch	10.20
. Benzotriazoles -				
Tinuvin 327	2-(3',5'-di-t-butyl-2'-hydroxy phenyl)-5-chlorobenzotriazole	UV absorber	Ciba Geigy	9.75
Tinuvin P	2-(2'-hydroxy-5'-methyl phenyl) benzotriazole	UV absorber	Ciba Geigy	9.25
. Nickel Complexes -				
AM-105	Nickel bisoctyl phenol sulfide	Excited state quencher	Ferro	3.85
Cyasorb UV-1084	[2,2'-thiobis(4-t-octyl phenolato)] n-butyl-amine Nickel II	Excited state quencher	American Cyanamid	5.65
Irgastab 2002	Nickel bis [O-ethyl(3,5-di-t-butyl-4-hydroxy-benzyl)] phosphate	Excited state quencher	Ciba Geigy	8.10
. Acrylonitriles -				
UV Absorber 340	N-(β -cyano- β -carbo-methoxy vinyl)-2-methylindoline	UV absorber	Mobay	10.99

...Continued

TABLE 4-1 (Continued - 2)

Trade Name	Chemical Name	Function	Manufacturer	Price (\$/Lb)
Acrylonitriles (Continued) -				
Uvinul N-35	Ethyl-2-cyano-3,3-di-phenyl acrylate	UV absorber	GAF	8.10
Uvinul N-539	2-ethyl hexyl-2-cyano-3,3-diphenyl acrylate	UV absorber	GAF	6.40
. Benzylidene Malonates -				
Cyasorb UV-1988	(p-methoxybenzylidene) malonic acid, dimethyl ester	UV absorber	American Cyanamid	12.60
Cyasorb UV-3100	(p-methoxybenzylidene) malonic acid, diethyl ester	UV absorber	American Cyanamid	7.60
. Benzoate Esters -				
AM-340	2,4-di-t-butylphenyl-3,5-di-t-butyl-4-hydroxybenzoate	Radical deactivator	Ferro	4.75
Inhibitor RMB	Resorcinol monobenzoate	UV absorber	Eastman	3.47
. Salicylates -				
Inhibitor OPS	p-octylphenyl salicylate	UV absorber	Eastman	Discontinued
Salol	Phenyl salicylate	UV absorber	Dow	2.15
t-Butyl Salol	4-t-butyl phenyl salicylate	UV absorber	Dow	3.60
. Amine -				
Tinuvin 770	Hindered amine	Radical deactivator	Ciba Geigy	13.20

TABLE 4-2

Antioxidants

Trade Name	Chemical Name	Functions	Manufacturer	Price (\$/Lb)
<u>. Alkylated Mono-Phenols</u>				
Ionol	2,6-di-t-butyl-4-methyl phenol	Free-radical scavenger	Shell	1.06
Irganox 1076	Octadecyl 3-(3',5'-di-t-butyl-4'-hydroxyphenyl) propionate	Free-radical scavenger	Ciba-Geigy	3.60
Irganox 1093	O,O-di-n-octadecyl-3,5,-di-t-butyl-4-hydroxybenzyl phosphonate	Free-radical scavenger	Ciba-Geigy	6.70
<u>. Alkylated Bis-Phenols</u>				
Cyanox 2246	2,2'-methylene bis-(4-methyl-6-t-butylphenol)	Free-radical scavenger	American Cyanamid	1.81
Santonox R	4,4'-thiobis-(6-t-butyl metacresol)	Free-radical scavenger; peroxide decomposer	Monsanto	3.40
Irganox 565	2,4-bis(n-octylthio)-6-(4-hydroxy-3,5-di-t-butyl anilino)-1,3,5-triazine	Free-radical scavenger; peroxide decomposer	Ciba-Geigy	(a)
Santowhite	4,4'-butylidene bis(6-t-butyl m-cresol)	Free-radical scavenger	Monsanto	2.27
<u>. Alkylated Poly-Phenols</u>				
Good-rite 3125	3,5-di-t-butyl-4-hydroxycinnamic acid triester with 1,3,5-tris(2-hydroxyethyl) triazine-2,4,6-trione	Free-radical scavenger	Goodrich	5.00
Irganox 1010	Tetrakis [methylene 3-(3',5'-di-t-butyl-4'-hydroxyphenyl) propionate] methane	Free-radical scavenger	Ciba-Geigy	5.40
Antioxidant 330	1,3,5-trimethyl-2,4,6-tris(3,5-di-t-butyl-4-hydroxybenzyl) benzene	Free-radical scavenger	Ethyl	5.30

(a) Development product

...Continued

TABLE 4-2(Continued - 2)

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OF POOR QUALITY

Trade Name	Chemical Name	Functions	Manufacturer	Price (\$/Lb)
• Alkylated Poly-Phenols (Continued)				
Topanol CA	3:1 condensate of 3-methyl-6-t-butylphenol with crotonaldehyde	Free-radical scavenger	ICI	3.89
CAO-30	1,1'-thio bis(2-naphthol)	Free-radical scavenger	Ashland	3.00
• <u>Thiodipropionates</u>				
Cyanox LTDP	Dilaurylthiodipropionate	Peroxide decomposer	American Cyanamid	1.31
Cyanox STDP	Distearylthiodipropionate	Peroxide decomposer	American Cyanamid	1.33
Cyanox 711	Ditridecylthiodipropionate	Peroxide decomposer	American Cyanamid	0.96
• <u>Organic Phosphites</u>				
Polygard	Tri(mixed mono- and dinonyl)	Peroxide decomposer and metal deactivator	Uniroyal	0.62
Wytox 438	Polymeric phosphite	Same	Stepan	0.66
Weston 618	Di(stearyl) pentaerythrityl diphosphite	Same	Borg-Warner	2.45
• <u>Amines</u>				
Agerite White	Sym. dibetanaphthyl-p-phenylenediamine	Free-radical scavenger; copper inhibitor	Vanderbilt	2.59
JZF	N,N'-diphenyl-p-phenylene diamine	Same	Uniroyal	2.07
• <u>Miscellaneous Metal Deactivators</u>				
CHEL 130	Proprietary	Metal deactivator	Ciba-Geigy	6.75
Mark 1475	Proprietary triazole	Same	Argus	11.70
• <u>Dithiocarbamate</u>				
Ethyl Zimate	Zinc diethyldithiocarbamate	Peroxide decomposer	Vanderbilt	1.06

TABLE 4-3

UV Upgrade - Hardness
ASTM D-2240 - Shore A and D

Base Resin	Serial Number	Upgrade Formula	Control	Weather-Ometer 120 Days	RS-4, 55°C 120 Days
Lexan	9030-112(Y)	9030	D 70/69	D 74/68	D 69/66
Lexan	4852A	A	D 70/69	D 72/66	D 69/66
Lexan	4852E	B	D 68/67	D 80/75	D 71/66
CAB	4858A	485	D 53/52	D 62/57	D 59/54
CAB	4852B	A	D 57/54	D 54/58	D 61/56
CAB	4853G	C	D 61/59	D 68/63	D 52/48
V-811	4857I	UVA5	D 72/71	D 70/65	D 74/67
V-811	4852D	A	D 68/67	D 72/65	D 73/67
V-811	4853H	C	D 71/69	D 74/64	D 74/68
C-4	4853I	C	D 71/69	D 71/66	D 68/62
C-4	4852F	B	D 69/68	D 70/66	D 69/63
C-4	4852C	A	D 67/65	D 68/53	D 68/62
DR61	4854A	A	D 71/69	D 70/66	D 71/64
DR61	4854C	B	D 71/69	D 69/63	D 73/66
DR61	4854B	C	D 61/69	D 70/65	D 71/67

TABLE 4-4

UV Upgrade - Optical Transmission

Ultraviolet Range - 280-350 nm
Stabilized Vs. Unstabilized Materials

Resin	Serial Number	Upgrade Formula	Unaged Controls (T%)		Weather-Ometer (T%)						RS-4 Sunlamp, 55°C (T%)			
			Unst. Sta.		120 Days		240 Days		120 Days		240 Days			
Unst.	Sta.	Unst.	Sta.	Unst.	Sta.	Unst.	Sta.	Unst.	Sta.	Unst.	Sta.			
Lexan	9030-112(Y)	9030	0	0	0	0	0	(c)	1	0	NT	(c)		
Lexan	4852A	A	0	0	0	0	0	(c)	1	0	NT	(c)		
Lexan	4852E	B	0	0	0	0	0	(c)	1	0	NT	(c)		
CAB	4858A	485	44	0	(a)	0	(a)	(b)	(a)	0	(a)	0		
CAB	4852B	A	44	0	(a)	0	(a)	0	(a)	0	(a)	0		
CAB	4853G	C	44	0	(a)	0	(a)	(b)	(a)	0	(a)	(b)		
V-811	48571	UVA5	75	0	56	0	78	0	76	0	(b)	0		
V-811	4852D	A	75	0	56	0	78	0	76	0	(b)	0		
V-811	4853H	C	75	0	56	0	78	0	76	0	(b)	0		
C-4	4853I	C	50	0	43	0	23	(c)	54	0	42	(c)		
C-4	4852F	B	50	0	43	0	23	(c)	54	0	42	(c)		
C-4	4852C	A	50	0	43	0	23	(c)	54	0	42	(c)		
DR61	4854A	A	0	0	0	0	39	(c)	2	0	5	(c)		
DR61	4854C	B	0	0	0	0	39	(c)	2	0	5	(c)		
DR61	4854B	C	0	0	0	0	39	(c)	2	0	5	(c)		

(a) Melted/flowed
(b) Broken/shattered
(c) Discontinued

NT = Not tested

TABLE 4-5

UV Upgrade - Optical Transmission
Visible Range - 350-800 nm
Stabilized Vs. Unstabilized Materials

Resin	Serial Number	Upgrade Formula	Unaged Controls (T%)		Weather-Ometer (T%)				RS-4 Sunlamp, 55°C (T%)			
			Unst.	Sta.	Unst.	Sta.	Unst.	Sta.	Unst.	Sta.	Unst.	Sta.
Lexan	9030-112(Y)	9030	88	83	53	42	38	(c)	73	61	NT	(c)
Lexan	4852A	A	88	77	53	70	38	(c)	73	74	NT	(c)
Lexan	4852E	B	88	79	53	71	38	(c)	73	72	NT	(c)
CAB	4858A	485	91	87	(a)	85	(a)	(b)	(a)	83	(a)	(a)
CAB	4852B	A	91	84	(a)	77	(a)	26	(a)	85	(a)	86
CAB	4853G	C	91	81	(a)	79	(a)	(b)	(a)	80	(a)	(b)
V-811	4857I	UVA5	92	91	79	87	81	82	84	89	76	88
V-811	4852D	A	92	85	79	83	81	72	84	85	76	85
V-811	4853H	C	92	84	79	84	81	76	84	85	76	85
C-4	4853I	C	91	87	66	86	52	(c)	77	85	67	(c)
C-4	4852F	B	91	81	66	79	52	(c)	77	82	67	(c)
C-4	4852C	A	91	79	66	78	52	(c)	77	82	67	(c)
DR61	4854A	A	90	81	80	80	78	(c)	80	84	80	(c)
DR61	4854C	B	90	85	80	71	78	(c)	80	87	80	(c)
DR61	4854B	C	90	85	80	87	78	(c)	80	86	80	(c)

(a) Melted/Flowed

NT = Not tested

(b) Brittle/broken

(c) Discontinued

TABLE 4-6

UV Upgrade
Mechanical Property: Yield (psi)

ASTM D-1708

Stabilized Vs. Unstabilized Controls																
Base Resin	Serial Number	Upgrade Formula	Unaged Controls (T%)		Weather-Ometer (T%)						RS-4 Sunlamp, 55°C (T%)					
			Unst. Sta.		120 Days		240 Days		120 Days		240 Days		120 Days		240 Days	
Lexan	9030(Y)	9030	8500	8427	8950	NY	(c)	(c)	9570	NY	(c)	(c)	(c)	(c)	(c)	
Lexan	4852A	A	8500	9420	8950	NY	(c)	(c)	8469	NY	(c)	(c)	(c)	(c)	(c)	
Lexan	4852E	B	8500	9430	8950	NY	(c)	(c)	9570	NY	(c)	(c)	(c)	(c)	(c)	
CAB	4858A	485	3470	3460	(a)	NY	(a)	NY	(a)	3740	(a)	(a)	(a)	(a)	(a)	
CAB	4852B	A	3470	3760	(a)	NY	(a)	NY	(a)	NY	(a)	(a)	(a)	(a)	NY	
CAB	4853G	C	3470	3875	(a)	NY	(a)	(a)	(a)	(b)	(a)	(a)	(a)	(a)	(a)	
V-811	4857I	UVA5	9030	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY	
V-811	4852D	A	9030	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY	
V-811	4853H	C	9030	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY	
C-4	4853I	C	5320	5360	5560	NY	5636	(c)	5830	5689	5763	5763	(c)	(c)	(c)	
C-4	4852F	B	5320	5460	5560	5949	5636	(c)	5830	NY	5763	5763	(c)	(c)	(c)	
C-4	4852C	A	5320	5800	5560	5588	5636	(c)	5830	5754	5763	5763	(c)	(c)	(c)	
DR61	4854A	A	5630	5540	5690	5499	NY	(c)	NY	NY	NY	NY	(c)	(c)	(c)	
DR61	4854C	B	5630	5240	5690	5161	NY	(c)	NY	NY	NY	NY	(c)	(c)	(c)	
DR61	4854B	C	5630	5440	5690	NY	NY	(c)	NY	NY	NY	NY	(c)	(c)	(c)	

(a) Melted/flowed (c) Discontinued

(b) Brittle/broken NY = No yield

TABLE 4-7

UV Upgrade

Mechanical Property: Modulus (psi x 10⁵)

ASTM D-1708

Stabilized Vs. Unstabilized Materials

Base Resin	Serial Number	Upgrade Formula	Unaged Controls (T%)		Weather-Ometer (T%)		RS-4 Sunlamp, 55°C (T%)			
							120 Days		240 Days	
			Unst.	Sta.	Unst.	Sta.	Unst.	Sta.	Unst.	Sta.
Lexan	9030(Y)	9030	3.14	2.81	3.53	2.99	(c)	3.84	3.04	(c)
Lexan	4852A	A	3.14	3.53	3.53	3.84	(c)	3.84	4.08	(c)
Lexan	4852E	B	3.14	3.55	3.53	3.37	(c)	3.84	4.00	(c)
CAB	4858A	485	1.54	1.46	(a)	1.47	(a)	(a)	1.37	(a)
CAB	4852B	A	1.54	1.39	(a)	1.51	(a)	(c)	1.41	(a)
CAB	4853G	C	1.54	1.49	(a)	1.27	(a)	(a)	(b)	(a)
V-811	4857I	UVA5	4.18	4.79	4.26	4.5	4.5	(c)	4.57	5.02
V-811	4852D	A	4.18	4.54	4.26	3.94	4.5	(c)	4.57	5.20
V-811	4853H	C	4.18	5.05	4.26	4.25	4.5	(c)	4.57	4.86
C-4	4853I	C	1.67	2.08	2.40	2.06	2.4	(c)	2.52	2.06
C-4	4852F	B	1.67	2.21	2.40	2.49	2.4	(c)	2.52	2.53
C-4	4852C	A	1.67	2.48	2.40	2.10	2.4	(c)	2.52	2.45
DR61	4854A	A	2.20	2.29	2.56	2.06	2.5	(c)	2.66	2.24
DR61	4854C	B	2.20	2.07	2.56	2.04	2.5	(c)	2.66	2.12
DR61	4854B	C	2.20	2.37	2.56	2.07	2.5	(c)	2.66	2.24

(a) Melted/flowed

(b) Brittle/broken

(c) Discontinued

TABLE 4-8

UV Upgrade

Mechanical Property: Elongation, Percent
Stabilized Vs. Unstabilized Materials

Base Resin	Serial Number	Upgrade Formula	Unaged Controls (%)		Weather-Ometer (T%)				RS-4 Sunlamp, 55°C (T%)			
			Unst.	Sta.	120 Days		240 Days		120 Days		240 Days	
					Unst.	Sta.	Unst.	Sta.	Unst.	Sta.	Unst.	Sta.
Lexan	9030(Y)	9030	104	128	22	1	(c)	(c)	16	1	(c)	(c)
Lexan	4852A	A	104	10	22	3	(c)	(c)	16	4	(c)	(c)
Lexan	4852E	B	104	10	22	3	(c)	(c)	16	4	(c)	(c)
CAB	4858A	485	81	55	(a)	17	(a)	(a)	(a)	22	(a)	(a)
CAB	4852B	A	81	65	(a)	20	(a)	1.8	(a)	3	(a)	2.2
CAB	4853G	C	81	40	(a)	11	(a)	(a)	(a)	(b)	(a)	(a)
V-811	4857I	UVA5	5	2	3	2	2	1.1	2	2	1.5	5.2
V-811	4852D	A	5	2	3	2	2	1.1	2	1	1.5	2.2
V-811	4853H	C	5	2	3	2	2	4.4	2	2	1.5	5.8
C-4	4853I	C	49	25	40	8	21	(c)	16	9	14	(c)
C-4	4852F	B	49	20	40	9	21	(c)	16	5	14	(c)
C-4	4852C	A	49	20	40	11	21	(c)	16	6	14	(c)
DR61	4854A	A	17	35	10	12	4	(c)	5	3	1	(c)
DR61	4854C	E	17	35	10	8	4	(c)	5	2	1	(c)
DR61	4854B	C	17	30	10	6	4	(c)	5	4	1	(c)

(a) Melted/flowed

(b) Brittle/broken

(c) Discontinued

TABLE 4-9

UV Upgrade

Mechanical Property: Tensile Strength

Stabilized Vs. Unstabilized Materials

Base Resin	Serial Number	Upgrade Formula	Unaged Controls (%)		Weather-Ometer (%)				RS-4 Sunlamp, 55°C (%)			
					120 Days		240 Days		120 Days		240 Days	
			Unst.	Sta.	Unst.	Sta.	Unst.	Sta.	Unst.	Sta.	Unst.	Sta.
Lexan	9030(Y)	9030	8160	8818	7220	8345	(c)	(c)	7540	8655	(c)	(c)
Lexan	4852A	A	8160	7860	7220	6388	(c)	(c)	7540	7786	(c)	(c)
Lexan	4852E	B	8160	7990	7220	5649	(c)	(c)	7540	8203	(c)	(c)
CAB	4858A	485	4400	3680	(a)	1883	(a)	(a)	(a)	3117	(a)	(a)
CAB	4852B	A	4400	3870	(a)	3168	(a)	1060	(a)	3313	(a)	1557
CAB	4853G	C	4400	3770	(a)	1599	(a)	(a)	(a)	(b)	(a)	(a)
V-811	4857I	UVA5	9030	6450	6190	6637	7200	6314	6040	5934	2961	2669
V-811	4852D	A	9030	8100	6190	4704	7200	3156	6040	4277	2961	3117
V-811	4853H	C	9030	6650	6190	5150	7200	4431	6040	4807	2961	2768
C-4	4853I	C	5570	5030	5120	5591	5064	(c)	5000	5224	3228	(e)
C-4	4852F	B	5570	5030	5120	5387	5064	(c)	5000	5457	3228	(c)
C-4	4852C	A	5570	5260	5120	5430	5064	(c)	5000	5467	3228	(c)
DR61	4854A	A	5380	5350	5400	5247	3208	(c)	4530	4320	1525	(c)
DR61	4854C	B	5380	5000	5400	5376	3208	(c)	4530	3767	1525	(c)
DR61	4854B	C	5380	5300	5400	5700	3208	(c)	4530	4815	1525	(c)

(a) Melted/Flowed

(b) Brittle/broken

(c) Discontinued

TABLE 4-10

UV Upgrade

Mechanical Properties - Tedlar Protection *

ASTM D-1708

Base Resin	Serial Number	Upgrade Formula	Unaged Controls		Weather-Ometer (T%)				RS-4 Sunlamp, 55°C (T%)			
					120 Days		240 Days		120 Days		240 Days	
			Unst.	Sta.	Unst.	Sta.	Unst.	Sta.	Unst.	Sta.	Unst.	Sta.
Yield (psi) Plexiglas Tenite	V-811 479	Tedlar Tedlar	9030	9030	NY	5262	NY	5053	NY	6328	NY	4841
			3470	3470	(a)	3380	(a)	NY	(a)	3807	(a)	(b)
Modulus (psi x 10 ⁵) Plexiglas Tenite	V-811 479	Tedlar Tedlar	4.18	4.18	4.26		4.5		4.57		3.26	(b)
			1.54	1.54	(a)		(a)		(a)		(a)	
Elongation (%) Plexiglas Tenite	V-811 479	Tedlar Tedlar	5	5	3	7.3	2	6.3	2	6.2	1.5	5.1
			81	81	(a)	26.7	(a)	2.7	(a)	30	(a)	(b)
Tensile Strength (psi) Plexiglas Tenite	V-811 479	Tedlar Tedlar	9030	9030	6190	5070	7200	4051	6040	6669	2961	5170
			4400	4400	(a)	2835	(a)	1147	(a)	3364	(a)	(b)

NY = No yield

* Specimens protected by a 1-mil film of Tedlar
100BG30 UT ultraviolet absorbing film.

- (a) Melted/flowed
(b) Brittle/broken
(c) Discontinued

TABLE 4-11

UV Upgrade

Mechanical Properties - UV-Acryloid Protection*

ASTM D-1708

Base Resin	Serial Number	Upgrade Formula	Unaged Controls		Weather-Ometer (T%)				RS-4 Sunlamp, 55° C (T%)				
					120 Days		240 Days		120 Days		240 Days		
			Unst.	Sta.	Unst.	Sta.	Unst.	Sta.	Unst.	Sta.			
. Yield (psi)													
Plexiglas	V-811 479	Acryloid	9030	9030	NY	NY	NY	NY	NY	NY	NY	NY	NY
Tenite		Acryloid	3470	3470	(a)	481	(a)	2100	(a)	(a)	(a)	(a)	(a)
. Modulus (psi x 10 ⁵)													
Plexiglas	V-811 479	Acryloid	4.18	4.18	4.26		4.5		4.57		3.26		
Tenite		Acryloid	1.54	1.54	(a)		(a)	(a)	(a)		(a)		(a)
. Elongation (%)													
Plexiglas	V-811 479	Acryloid	5	5	3	8.9	2	2	2	8.2	1.5	4.8	
Tenite		Acryloid	81	81	(a)	9.4	(a)	(a)	(a)	9.3	(a)	(a)	(a)
. Tensile Strength (psi)													
Plexiglas	V-811 479	Acryloid	9030	9030	6190	4832	7200	4032	6040	5165	2961	5130	
Tenite		Acryloid	4400	4400	(a)	218	(a)	(a)	(a)	1698	(a)	(a)	(a)

(a) Melted/flowed

(b) Brittle/broken

(c) Discontinued

NY = No yield

* Specimens protected by a 1-mil coating of acrylic coating containing UV absorber.

TABLE 4-12

UV Upgrade

Optical Properties

Stabilized Vs. Unstabilized Materials

Base Resin	Serial Number	Upgrade Formula	Unaged Controls		Weather-Ometer (T%)				RS-4 Sunlamp, 55°C (T%)			
					120 Days		240 Days		120 Days		240 Days	
			Unst.	Sta.	Unst.	Sta.	Unst.	Sta.	Unst.	Sta.	Unst.	Sta.
. Visible Transmission - 350-800 nm												
Plexiglas Tenite	V-811 479	Tedlar ^(d) Tedlar	92	-	79	92	81	92	84	92	76	91
			92	-	(a)	92	(a)	93	(a)	93	(a)	85
Plexiglas Tenite	V-811 479	Acryloid ^(e) Acryloid	92	-	79	68	81	65	84	88	76	(a)
			92	-	(a)	65	(a)	(a)	(a)	87	(a)	(a)
. Ultraviolet Transmission - 290-350 nm												
Plexiglas Tenite	V-811 479	Tedlar Tedlar	75	-	56	50	78	48	76	56	(b)	48
			44	-	(a)	40	(a)	42	(a)	49	(a)	42
Plexiglas Tenite	V-811 479	Acryloid Acryloid	75	-	56	34	78	(a)	76	39	(b)	(a)
			44	-	(a)	14	(a)	(a)	(a)	4	(b)	(a)

NY = No yield

(a) Melted/flowed

(b) Brittle/broken

(c) Discontinued

(d) 100 BG30 UT Tedlar - UV absorbing

(e) Acryloid B44 acrylic containing UV absorbers

TABLE 4-13

Ultraviolet-Absorbing Coatings

(Based on Rohm & Haas Acrylics)

Formula A-6693-	(a) Acryloid Number	(b) Absorber	(c) Level (phr)	(d) Optical Transmission		(e) Cost	
				UV 290-350 nm	Visible 350-800 nm	\$/lb (Dry)	\$/ft ² / mil
1	B-44	Uvinul 400	2	6	81.7	1.248	0.0076
2	B-44	Uvinul 400	5	2	79.4	1.415	0.0086
3	B-44	Tinuvin-P	2	3	79.9	1.299	0.0079
4	B-44	Tinuvin-P	5	0	71.7	1.542	0.0094
5	B-72	Uvinul 400	2	11	83.7	1.368	0.0083
6	B-72	Uvinul 400	5	3	83.1	1.532	0.0093
7	B-72	Tinuvin-P	2	5	82.7	1.419	0.0086
8	B-72	Tinuvin-P	5	0	81.6	1.659	0.0102
9	B-82	Uvinul 400	2	9	83.5	1.200	0.0073
10	B-82	Uvinul 400	5	1	82.6	1.368	0.0083
11	B-82	Tinuvin-P	2	1	82.8	1.251	0.0076
12	B-82	Tinuvin-P	5	0	82.1	1.495	0.0092
13	B-44	Permasorb-MA	5	5	83.0	1.590	0.0097
14	B-44	Permasorb-MA	10	1	80.8	2.043	0.0125
15	B-72	Permasorb-MA	5	9	80.0	1.707	0.0104
16	B-72	Permasorb-MA	10	2	82.0	2.154	0.0132
17	B-82	Permasorb-MA	5	2	81.8	1.543	0.0094
18	B-82	Permasorb-MA	10	0	80.8	1.999	0.0122

(a) Solution acrylic coatings

(b) Absorber dissolves in acrylic solution by stirring at 60°C for 20 minutes. Formulations also contain 1% Cyasorb UV-1084 quencher for additional stability.

...Continued

TABLE 4-13 (Continued - 2)

Formula A-6693-	(a)	(b)	(c)	(d)		(e)	
	Acryloid Number	Absorber	Level (phr)	Optical Transmission	Cost		
				UV 290-350 nm	Visible 350-800 nm	\$/lb (Dry)	\$/ft ² / mil
<u>Comparative Materials:</u>							
UV-40	Saflex	Proprietary	?	0	75.2	-	-
BG30-UT	Tedlar	Proprietary	?	0	90 ^(f)	6.75	0.0482
UV-X	Llumar	Proprietary	?	0	88 ^(f)	6.50	0.044

(c) phr = Parts per hundred parts resin, based on solids content.

(d) Integrated transmissions on 1-mil films.

(e) Based on assumed average density of 1.18, or 0.0426 lb/in.³.

(f) Based on manufacturer's data for this film.

TABLE 4-14

Florida, Fixed Angle, 45° South

Time: 6 months

Exposure Testing

Langley's: 66,679

Resin	Optical Transmission (%)				Mechanical Properties								Remarks
	UV		Visible		Yield Str. (psi)		Modulus (psi x 10 ⁵)		Elongation (%)		Tensile Str. (psi)		
	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	
Halar 500	36	32	81	58	5030	5154	2.23	1.71	175	175	6090	7178	(a)
Tedlar 20	13	80	76	33	(b) 5820	8123	3.60	2.03	120	151	12,100	14,590	(a)
Plexi DR-61K	0	0	90	71	5630	5715	2.20	1.56	17	27	5380	5334	(a)
FEP-100	34	27	84	56	(b) 2130	2071	0.704	2.06	220	332	2800	3711	(a)
Tenite 479	44	(c)	92	(c)	3470	(c)	1.54	(c)	81	(c)	4400	(c)	(a)
Sylgard 184	32	20	76	50	NY	NY	(e) 586	(e) 1350	106	118	930	620	Dirt Accumulation
Kel-F 6060	24	48	82	64	5690	5327	1.72	1.12	130	81	5680	4787	(a)
Lexan 123	0	0	88	75	8500	9031	3.14	2.06	104	21	8160	7389	Yellow; hazy
Plexi V-811	75	63	92	72	9030	NY	4.18	2.22	5	4	9030	5252	(a)
Saflex PT, PVB	-	(d)	90	(d)	830	(d)	0.051	(d)	180	(d)	4010	(d)	Severe Flow
Q3-6527-Gel	-	-	92	-	(f)	-	(f)	-	(f)	-	(f)	-	Bubbles

Code: Cont. = Control (a) No visual change (d) Material flowed
 Exp. = Exposed (b) Pseudo yield point (e) Modulus at 100 percent, psi x 1
 Str. = Strength (c) Broken (f) Not testable
 NY = No Yield

TABLE 4-15

ENWAQUA Exposure

Langley's: 503,340

Time: 4 Months

Exposure Testing

Resin	Optical Transmission (%)				Mechanical Properties								Remarks
	UV		Visible		Yield Str. (psi)		Modulus 5 (psi x 10 ⁵)		Elongation (%)		Tensile Str. (psi)		
					Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	
Halar 500	36	29	81	62	5030	4483	2.23	2.1	175	182	6090	5285	(a)
Tedlar 20	13	4	76	19	(b) 5820	5754	3.60	2.29	120	145	12,100	10,446	(a)
Plexi DR-61K	0	1	90	75	5630	6120	2.20	2.32	17	13	5380	5763	(a)
FEP-100	34	35	84	65	(b) 2130	1913	0.704	0.71	220	263	2800	3269	(a)
Tenite 479	44	(c)	92	44	3470	NY	1.54	1.77	81	<1	4400	812	Embrittled
Sylgard 184	32	7	76	30	NY	NY	(a) 586	(e) 380	106	80	930	532	Dirt Accumulation
Kel-F 6060	24	18	82	57	5690	4447	1.72	1.64	130	70	5680	3861	(a)
Lexan 123	0	0	88	64	8500	8322	3.14	3.32	104	14	8160	6674	Yellow, hazy
Plexi V-811	75	72	92	79	9030	NY	4.18	4.37	5	2	9030	5520	(a)
Saflex, PT, PVB	-	(d)	90	(d)	830	(d)	0.051	(d)	180	(d)	4010	(d)	Yellow, flowed
Q3-6527-Gel	-	-	92	-	(f)	-	(f)	-	(f)	-	(f)	-	Bubbles

Code: Cont. = Control
 Exp. = Exposed
 Str. = Strength
 NY = No Yield

(a) No visual change
 (b) Pseudo yield point
 (c) Broken

(d) Material flowed
 (e) Modulus at 100 percent, psi x 1
 (secant modulus)
 (f) Not testable

TABLE 4-16

EMMAQUA Exposure

Desert Sunshine Exposure Tests, Inc.

Time: 8 Months

Langley: 937.740

Resin	Optical Transmission (%)				Mechanical Properties								Remarks
	UV		Visible		Yield Str. (psi)		Modulus (psi X 10 ⁵)		Elongation (%)		Tensile Str. (psi)		
											Tensile Str. (psi)		
	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	
Halar 500	36	7	81	51	5030	5047	2.23	1.41	175	144	6090	5307	(a)
Tedlar 20	13	1	76	31	(b) 5820	7469	3.60	1.56	120	132	12,100	13,364	(a)
Plexi DR-61K	0	1	90	72	5630	5643	2.20	1.51	17	11	5380	5360	(a)
PEP-100	34	21	84	73	(b) 2130	2634	0.704	4.29	220	327	2800	3518	(a)
Tenite 479	44	(c)	92	(c)	3470	(c)	1.54	(c)	81	(c)	4400	(c)	Disintegrated
Sylgard 184	32	11	76	36	NY	NY	(e) 586	(3) 1740	106	109	930	1017	Dirt Accumulation
Kel-P 6060	24	21	82	72	5690	5060	1.72	1.22	130	106	5680	4829	(a)
Lexan 123	0	0	88	52	8500	8491	3.14	2.10	104	14	8160	7012	Hazy, light yellow
Plexi V-811	75	53	92	76	9030	NY	4.18	2.28	5	4.7	9030	5100	(a)
Saflex PT, PVB	-	(d)	90	(d)	830	(d)	0.051	(d)	180	(d)	4010	(d)	Severe Flow
Q-36527-Gel	-	-	92	-	(f)	-	(f)	-	(f)	0	(f)	-	Bubbles

Code: Cont. = Control

Exp. = Exposed

Str. = Strength

NY = No Yield

(a) No visual change

(b) Pseudo yield point

(c) Broken

(d) Material flowed

(e) Modulus at 100 percent, psi X 1

(f) Not testable

TABLE 4-17
EXPOSURE TESTING
ELONGATION AT BREAK COMPARISON

Resin	Control (Unaged) (%)	% OF PROPERTY RETAINED				
		Florida 6 Months	Ensaqua 4 Months	Ensaqua 8 Months	RB-4 8 Months	Weather-0 Meter 8 Months
Halar 500	175	100	104	82	133	145
Tedlar 20	120	125	120	110	74	143
Plexi DR-61K	17	158	76	65	6	23
FEP-100	220	150	119	149	120	142
Tenite 479	81	(a)	~ 1	(a)	(a)	(b)
Sylgard 184	106	111	75	103	82	83
Kel-F 6060	130	62	54	81	118	127
Lexan 123	104	20	13	13	NT	NT
Plexi V-811	5	80	40	94	30	60
Saflex PT, PVB	180	(b)	(b)	(b)	(b)	(b)
Q3-6527	(c)	-	-	-	-	-

Code: (a) Broke/degraded
(b) Melted/flowed
(c) Not Testable
NT = Not Tested

TABLE 4-18
Exposure Testing
Tensile Strength Comparison

Resin	Control (Unaged) psi	% OF PROPERTY RETAINED				
		Florida 6 Months	Emmiqua 4 Months	Emmiqua 8 Months	RS-4 8 Months	Weather-0 Meter 8 Months
Halar 500	6090	117	87	87	109	113
Tedlar 20	12,100	120	86	110	59	84
Plexi DR-61K	5380	99	107	97	28	60
FEP-100	2800	132	117	126	89	96
Tenite 479	4499	(a)	18	(a)	(a)	(b)
Sylgard 184	930	66	57	109	60	50
Kel-F 6060	5680	84	68	85	101	96
Lexan 123	8160	91	82	86	NT	NT
Plexi V-811	9030	58	61	56	33	80
Saflex PT, PVB	4010	(b)	(b)	(b)	(b)	(b)
Q3-6527	(c)	-	-	-	-	-

Code: (a) Broken degraded
(b) Melted/flowed
(c) Not Testable

TABLE 4-19
Exposure Testing
Optical Transmission
Visible Range 350-800 nm

Resin	Control (Unaged) Transmittance	% OF PROPERTY RETAINED				
		Florida 6 Months	Zemaqua 4 Months	Zemaqua 8 Months	RS-4 8 Months	Weather-C Meter 8 Months
Halar 500	81	72	76	63	86	88
Tedlar 20	76	43	25	41	45	39
Plexi DR-61K	90	79	83	80	89	87
PEP-100	84	67	77	87	81	93
Tenite 479	92	(a)	48	(a)	(b)	(b)
Sylgard 184	76	66	39	47	84	34
Kel-P-6060	82	78	69	88	83	83
Lexan 123	88	85	73	59	NT	43
Plexi V-811	92	78	86	83	82	88
Saflex PT, P.B	90	(b)	(b)	(b)	(b)	(b)
Q3	(c)	-	-	-	-	-

Code: (a) Broken
(b) Melted/flowed
(c) Not Testable

TABLE 4-20

Mechanical Property/Temperature Variation

Property: Ultimate Tensile Strength (psi)

ASTM D-638

Resin	Manufacturer	Temperature					
		-20°C	0°C	23°C	40°C	60°C	80°C
Halar 500	Allied	8180	8470	8405	6015	5900	4950
Tedlar 20	DuPont	15,145	13,705	12,510	8060	7890	7785
Plexi DR-61K	Rohm & Haas	-	7705	5525	4355	2985	2300
FEP-100	DuPont	5275	4950	3860	3295	2070	1725
Tenite 479	Eastman	-	5070	4695	3555	3230	2165
Sylgard 184	Dow Corning	505	520	450	380	340	315
RTV 615	G.E.	775	510	460	570	405	730
Kel-F 6060	3M	8825	7330	5655	4150	3200	3025
PFA 9705	DuPont	4600	4615	4030	3010	3430	2680
Plexi V-811	Rohm & Haas	-	5925	9135	8240	5745	4225
Viton A-HV	DuPont	3060	NB ^(a)	NB ^(a)	NB ^(a)	115	90
C-4 Polycarbonate	Union Carbide	-	6675	5365	4455	3800	3035

(a) No break; elongation exceeds machine capacity.

TABLE 4-21

Mechanical Property/Temperature Variation

Property: Yield Strength (psi)
ASTM D-638

Resin	Manufacturer	Temperature					
		-20°C	0°C	23°C	40°C	60°C	80°C
Halar 500	Allied	7835	8145	5355	3780	2550	1495
Tedlar 20	DuPont	9790	9460	6140	3835	2875	2200
Plexi DR-61K	Rohm & Haas	-	^(a) 8200	6100	4865	2805	2390
FEP-100	DuPont	2935	2590	2145	1665	1305 ^(b)	970 ^(b)
Tenite 479	Eastman	-	5270	43	3090	2305	1650
Sylgard 184	Dow Corning	NY	NY	NY	NY	NY	NY
RTV 615	G.E.	NY	NY	NY	NY	NY	NY
Kel-F 6060	3M	NY	8675	5570	3990	2615	1770
PFA 9705	DuPont	2685	2530	1860	1730	1325 ^(b)	1055 ^(b)
Plexi V-811	Rohm & Haas	-	NY	NY	NY	6525	5250 ^(c)
Viton A-HV	DuPont	NY	NY	330	185	NY	NY
C-4 Polycarbonate	Union Carbide	-	NY	5480	4740	3915	3285

(a) Two samples yielded; one sample had no yield.

NY = No Yield

(b) Pseudo yield point

(c) Two samples had no yield; one sample yielded.

TABLE 4-22

Mechanical Property/Temperature Variation

Property: Modulus $\times 10^5$ psi

ASTM D-638

Resin	Manufacturer	Temperature					
		-20°C	0°C	23°C	40°C	60°C	80°C
Halar 500	Allied	1.64	2.50	1.50	1.30	0.91	0.24
Tedlar 20	DuPont	0.94	0.80	3.21	1.50	0.68	0.38
Plexi DR-61K	Rohm & Haas	-	1.28	2.90	2.35	1.35	1.10
FEP-100	DuPont	0.17	0.20	0.62	0.49	0.38	0.18
Tenite 479	Eastman	-	3.76	1.73	1.38	1.06	0.19
Sylgard 184 (a)	Dow Corning	100	120	230	330	270	335
RTV 615 (a)	G.E.	105	60	160	210	275	310
Kel-F 6060	3M	0.22	0.24	1.13	1.05	0.32	0.20
PFA 9705	DuPont	0.19	0.19	0.49	0.44	0.39	0.19
Plexi V-811	Rohm & Haas	-	1.20	4.98	4.60	3.49	2.36
Viton A-HV (a)	DuPont	7680	375	260	230	175	160
C-4 Polycarbonate	Union Carbide	-	6.22	2.25	2.65	2.25	2.16

(a) Secant Modulus, Figures shown indicate psi $\times 1.0$ at 50 percent elongation

TABLE 4-23

Mechanical Property/Temperature Variation

Property: Elongation at Break (%)

ASTM D-638

Resin	Manufacturer	Temperature					
		-20°C	0°C	23°C	40°C	60°C	80°C
Halar 500	Allied	285	290	275	265	365	445
Tedlar 20	DuPont	200	220	155	140	135	160
Plexi DR-61K	Rohm & Haas	-	20	25	45	90	150
FEP-100	DuPont	640	690	330	310	295	225
Tenite 479	Eastman	-	60	80	75	100	95
Sylgard 184	Dow Corning	230	210	110	70	85	65
RTV 615	G.E.	430	420	120	110	100	110
Kel-F 6060	3M	30	80	175	180	280	310
PFA 9705	DuPont	520	540	280	255	325	365
Plexi V-811	Rohm & Haas	-	20	5	5	10	15
Viton A-HV	DuPont	200	>700 ^(a)	>1000 ^(a)	>500 ^(a)	185	70
C-4 Polycarbonate	Un. on Carbide	-	30	50	45	60	75

(a) Elongation exceeds machine capacity